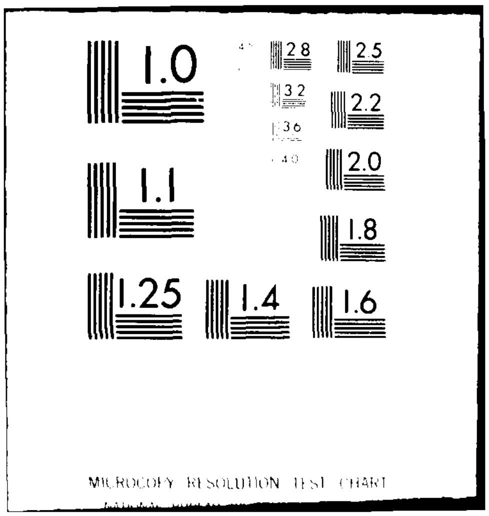
AD-A084 923 DECKER (J L) POTOMAC MD F/G 13/10
A FEASIBILITY STU"Y OF AIR CUSHION VEHICLE UTILIZATION IN COAST--ETC(U)
APR 80 J L DECKER DOT-CG-933571-A
UNCLASSIFIED USCG-D-25-80 NL

1 OF 2
ADA
084923


1.0
2.8
2.5
3.2
2.2
3.6
4.0
2.0
1.1
1.8
1.25
1.4
1.6
MICROCOPY RESOLUTION TEST CHART

REPORT NO. CG-D-25-80

A FEASIBILITY STUDY OF AIR CUSHION VEHICLE UTILIZATION IN COAST GUARD MISSIONS

J.L. Decker

12613 Newgate Road
Potomac, Maryland 20854

APRIL 1980

FINAL REPORT

Document is available to the U.S. Public through the
National Technical Information Service,
Springfield, Virginia 22161

PREPARED FOR

U.S. DEPARTMENT OF TRANSPORTATION

UNITED STATES COAST GUARD
OFFICE OF RESEARCH AND DEVELOPMENT
WASHINGTON, D.C. 20590

DISCLAIMER NOTICE

Technical Report Documentation Page

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
CG-D-25-80	AD-A084 923	

4. Title and Subtitle	5. Report Date
A Feasibility Study of Air Cushion Vehicle Utilization in Coast Guard Missions	Apr[redacted]80
	6. Performing Organization Code
	8. Performing Organization Report No.
7. Author(s): James L. Decker	
9. Performing Organization Name and Address	10. Work Unit No. (TRAIS)
J.L. Decker ~~Consultant~~ 12613 Newgate Road Potomac, Maryland 20854	11. Contract or Grant No. DOT-CG-933571-A
12. Sponsoring Agency Name and Address	13. Type of Report and Period Covered
United States Coast Guard Office of Research and Development Washington, D.C. 20590	14. Sponsoring Agency Code

15. Supplementary Notes

9) Final rept. 12)

16. Abstract

The subject investigation has studied the feasibility of air cushion vehicle (ACV) utilization in the performance of Coast Guard missions within the five program areas of Ice Management, Search and Rescue, Aids to Navigation, Marine Environmental Protection and Safety, Security, and Law Enforcement. In order to develop credible operational scenarios, the First and Ninth District operations were examined. The Voyageur ACV, as an existing craft, was compared with the 110' WYTM and the 140' WTGB in the First and Ninth Districts respectively. Effectiveness comparisons between the vehicle systems were made with respect to 12 relevant performance parameters and the potential annual utilization in mission operating hours was estimated for the ACV. The operating strengths of the ACV stem from its high speed, zero draft, and icebreaking capabilities. The weaker areas of the ACV capability relate to its towing bitt pull and endurance characteristics. It is estimated that the annual utilization of the ACV in mission operations is likely to exceed that of the existing Coast Guard cutters. A year around utilization is feasible. Hourly, annual and life cycle costs for the ACV operations have been developed within the study.

17. Key Words	18. Distribution Statement
Air Cushion Vehicle Coast Guard Missions Effectiveness Analysis Cost Analysis	Document is available to the U.S. Public through the National Technical Information Service, Springfield, Va. 22161

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price
Unclassified	Unclassified	123	

Form DOT F 1700.7 (8-72) Reproduction of completed page authorized

411 4??

TABLE OF CONTENTS

TABLE OF CONTENTS - CONT'D

SYMBOLS

C_R	Ice resistance coefficient
D	Propeller diameter, ft.
HP	Horsepower
J	Propeller advance ratio, V/n D
K_Q	Propeller torque coefficient, $Q/\rho_w n^2 D^5$
K_T	Propeller thrust coefficient, $T/\rho_w n^2 D^4$
MH	Manhours
OH	Vehicle operating hours
P.C.	Propulsive coefficient, R V/ 550 HP
Q	Engine or propeller torque
R	Vehicle resistance, lbs.
S	Evaluation score
T	Propeller thrust, lbs.
V	Vehicle velocity, ft./sec/ or knots
b	Vehicle beam, ft.
d	Ship draft, ft.
g	Gravity constant, ft./sec.^{2}
h	Level ice thickness, ft.
h_w	Wave height, ft.
n	Rotational speed, rev./sec.
l	Vehicle length, ft.
t	Thrust deduction factor
w	Wake velocity reduction factor into propeller

ρ	Density, slugs/cu. ft.
ρ_{Δ}	Difference in density between water and ice
	Ice flexural strength, lbs./sq. ft.
η	Propulsor efficiency for isolated propulsor

Subscripts

i	Ice
w	Water

I EXECUTIVE SUMMARY

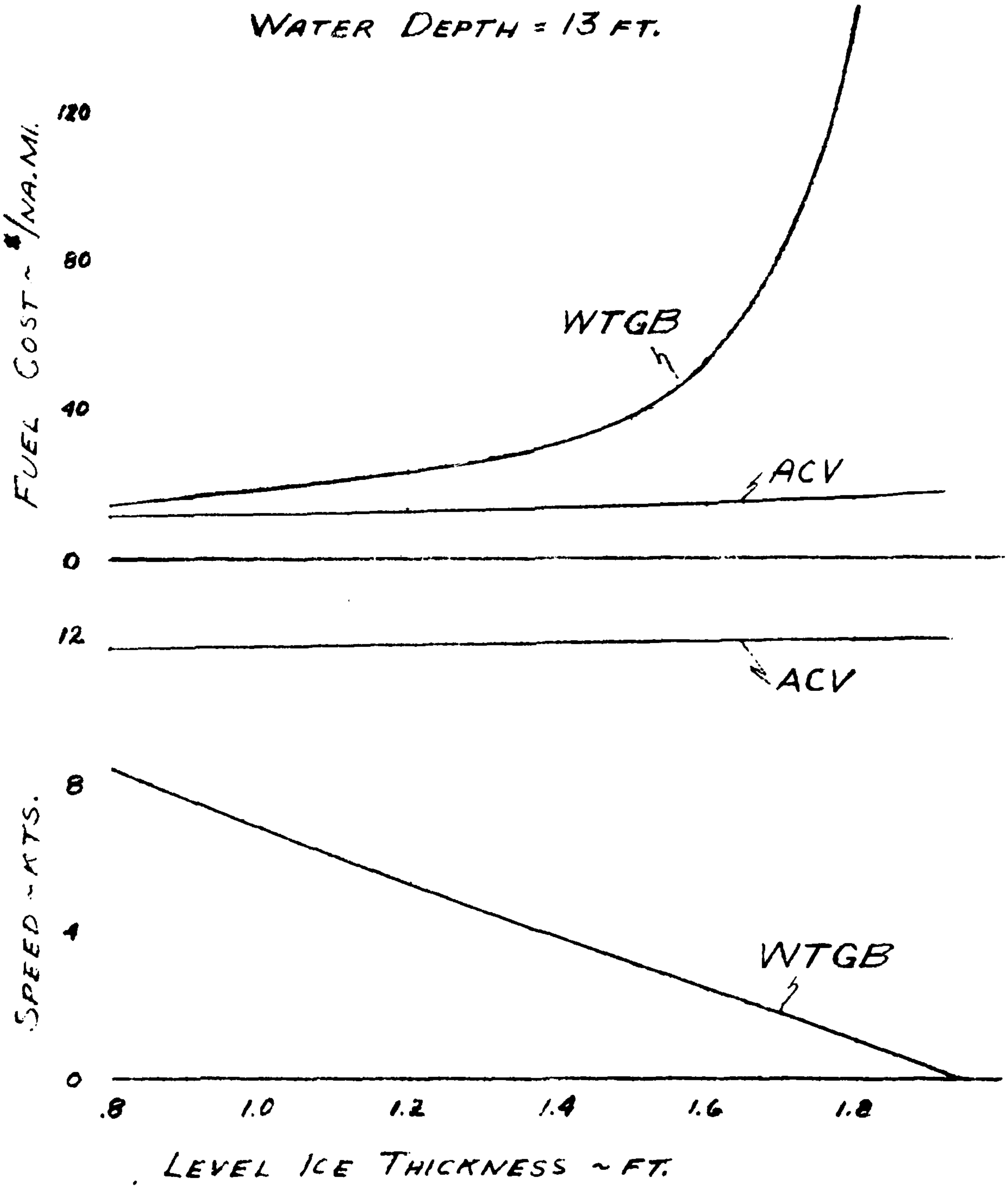
This examination into the feasibility of air cushion vehicle (ACV) utilization in Coast Guard missions has focused upon a comparison of the Voyageur ACV with the 110' WYTM class cutter in the First District, and a comparison of the Voyageur with the 140' WTGB class cutter in the Ninth District. The WYTM is nearing the end of its operational lifetime, and the WTGB is a new class cutter which has been introduced into Coast Guard service for approximately one year.

The acquisition cost of the WTGB ordered early in 1980 is in the $10 to $11 million range for the 662 ton cutter with its 2 500 HP propulsion system. The acquisition cost of the 40.5 ton Voyageur is $4.5 million, and the total normal rated power of its two gas turbine powerplants is 2 800 HP. Two used Voyageur ACV, refurbished with new skirts and rebuilt engines, are currently available at a price of $2 130 000 per craft.

The WTGB and the Voyageur ACV are comparable in their ability to break level ice. For the ice strength and stiffness parameters which were analyzed herein, level ice of 23 inch thickness will be broken in continuous motion by both vehicles. The conventional icebreaker and air cushion vehicle icebreakers break ice by quite different physical phenomena, and the resulting broken ice channel characteristics are somewhat different. At ice thicknesses which are near the limiting capability of a conventional icebreaker, a clear channel of a width which is moderately greater than the ship beam is produced. The variation of the icebreaking speed with level ice thickness for the WTGB is shown in Fig. 1-1. On the other hand, an ACV icebreaker produces a wide broken ice channel in which the broken ice remains largely in place. (See Fig. 3-9) The Voyageur broken ice channel width is approximately 110 feet for the 23 inch thick level ice. The icebreaking speed of

FIG. 1-1

COMPARATIVE ICEBREAKING PERFORMANCE
OF THE WTGB AND VOYAGEUR ACV



an ACV increases with ice thickness in deep water, and is reduced as the water depth beneath the ice sheet becomes shallower. The icebreaking speed of the Voyageur at a water depth of 13 feet is also shown in Fig. 1-1. The 13 foot depth has been chosen for this chart since it represents the minimum water depth for WTGB operations due to cutter draft limitations.

At level ice thickness values near 1.0 foot, the fuel cost of the ACV, at $12 per na. mi., is approximately $4 per na. mi. less than that of the WTGB as shown in Fig. 1-1. However, at an ice thickness of 1.8 feet, the ACV fuel cost at $16 per na. mi., is but a small fraction of the WTGB fuel cost of $140 per na. mi. The corresponding WTGB speed reduction from 8.4 knots to 1.0 knot is responsible for the rapidly increasing cost of fuel per mile of icebreaking for the cutter. This fuel cost analysis reflects the fact that the JP-5 fuel used in the Voyageur ACV is currently priced at 5¢ per gallon above the diesel fuel used in the WTGB when purchased by the government.

The open water maximum speed of the WTGB is 14.7 knots, while that of the Voyageur is approximately 45 knots in the normal weight range of the ACV.

The evaluation of the WYTM, WTGB and the Voyageur ACV against the Coast Guard program requirements has identified the strengths and weaknesses of the three vehicles and these results have been summarized in Table 1-1.

The high speed and freedom from draft limitations of the ACV appear to be particularly significant in the law enforcement, search and rescue, and icebreaking missions. For example, fishing vessel breakout from harbor ice has been inhibited in the First District due to the draft limitations

of the WYTM. On the other hand, the Voyageur ACV thrust level of 6 600 lbs. limits its towing ability to craft of less than 48 tons displacement. The ACV range of 1 000 na. mi. and endurance of 24 - 36 hours are less than the required values for some Coast Guard operations, and are well under the 4 000 na. mi. range of the WTGB.

Table 1 - 1

Vehicle Evaluation Against Coast Guard Program Requirements

District	Vehicle	Main Strengths	Main Weaknesses
First	WYTM	Range Endurance Towing Bitt Pull	Speed Draft
	Voyageur ACV	Draft Speed Icebreaking Capability Payload Capability	Endurance Towing Bitt Pull
Ninth	WTGB	Range Endurance Sea State Capability Payload Capability Towing Bitt Pull	Speed Draft
	Voyageur ACV	Draft Payload Capability Sea State Capability Response Time	Endurance Towing Bitt Pull

It should be noted that neither the Voyageur ACV nor the WTGB cutter meets the four foot icebreaking capability requirement of the Ninth District.

It is expected that the annual utilization of the Voyageur ACV in both the First and Ninth District operations would exceed that of the WYTM and WTGB cutters in view of the operational capability and flexibility which result from the ACV speed and zero draft characteristics.

A Voyageur ACV unit complement of 12 men is considered adequate to meet the operating and maintenance requirements when the craft is operated from an existing Coast Guard installation. A four man operating crew, sufficient to man two watches, and an eight man maintenance crew requirements are projected.

The operating costs of the Voyageur ACV, based upon the acquisition of a new craft at a cost of $4 500 000, are shown on annual and per operating hour bases in Table 1-2, for the First District, and Table 1-3 for the Ninth District.

Table 1 - 2

Voyageur ACV Operating Costs in the First District

Item	Annual Operating Cost	Hourly Operating Cost
Capital Charge	$150 000	$ 128.60
Maintenance	385 570	330.68
Crew (Operating)	96 000	82.33
Fuel	193 570	166.00
Total	$825 140	$ 707.61

Table 1 - 3

Voyageur ACV Operating Costs in the Ninth District

Item	Annual Operating Cost	Hourly Operating Cost
Capital Charge	$225 000	$ 119.10
Maintenance	565 120	299.01
Crew (Operating)	96 000	50.79
Fuel	313 740	166.00
Total	$1 199 860	$ 634.90

Note: January 1980 price levels employed.

II INTRODUCTION

In recent years, the ability of air cushion vehicles (ACV) to break surprising thicknesses of ice at high speeds has been demonstrated in operations of the Voyageur ACV by the Canadian Coast Guard. The 40 ton Voyageur has broken ice up to 41.5 inches thick when operating at the open water edge of an ice sheet in the waters in and around the St. Lawrence River. The phenomenon of high speed icebreaking with ACV is unusual in that the icebreaking speed increases with the ice sheet thickness. The effect of shallow water under the ice sheet is to cause a reduction in the ACV icebreaking speed.

The icebreaking and ice clearing ability of the ACV has opened up the possibility of effective year around operations with the vehicle in the accomplishment of Coast Guard missions. The high speed capabilities of the ACV, with speeds in the 40 to 50 knot range, in conjunction with its ability to operate in shallow water and overland, add to its versatility and flexibility for Coast Guard applications in each of the Coast Guard program areas. This operational potential of the ACV has led to the study which is reported herein, and which has as its purpose the examination of the feasibility of air cushion vehicle utilization in the accomplishment of the Coast Guard programs.

Within the study, the Voyageur ACV is compared with the new 140' WTGB Coast Guard cutter for operations in the Ninth District, and with the 110' WYTM for operations in the First District. The Voyageur level icebreaking capability is closely similar to that of the WTGB with its bubbler system in operation, thereby affording an equitable evaluation base between an ACV and an existing displacement hull cutter.

The general arrangement of the Voyageur ACV is shown in Fig. 2-1, and the leading particulars of the craft are listed in Table 2-2. The Voyageur has been designed so that it may be disassembled into modules which may be transported on a C-130 transport aircraft.

A comparison of the main design characteristics of the Voyageur ACV, the WTGB and the WYTM is shown in Table 2-1.

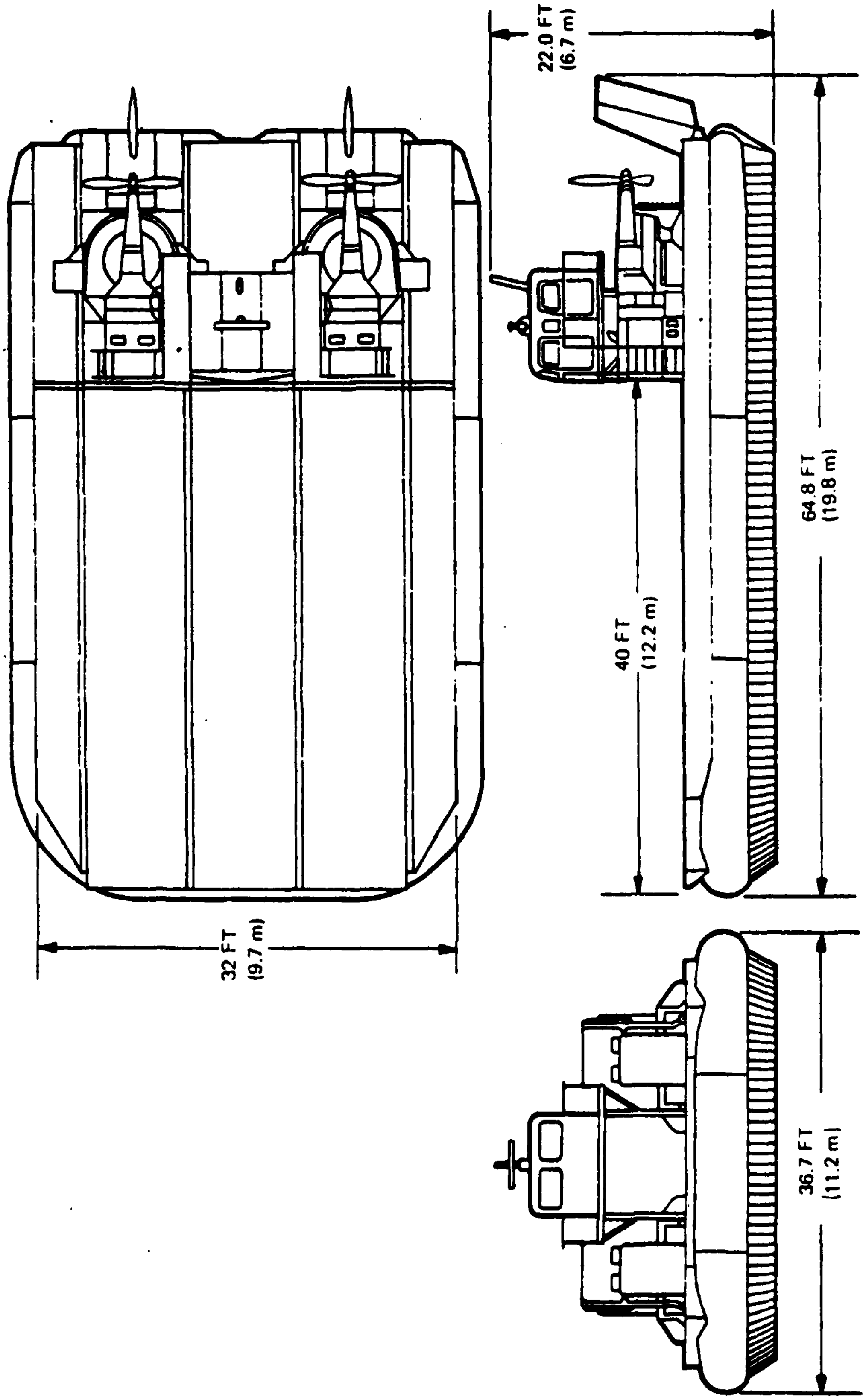
Table 2 - 1

Comparison of the Main Design Characteristics of Several Craft

		WTGB	Voyageur ACV	WYTM
Displacement	tons	662	40.5	400
Length Overall	ft.	140	64.8	110
Beam	ft.	37.5	36.7	27.2
Draft	ft.	12	0 *	11.5
Shaft Horsepower		2 500	3 400	1 000
Maximum Speed	kts.	14.7	45	12.5
Range	nm.	4 000	1 050	3 000

* The Voyageur draft is 0 feet on cushion and 0.9 feet off cushion.

Fig. 2 - 1



General Arrangement - Voyageur

Table 2 - 2

Voyageur Leading Particulars

SPECIFICATIONS

Bell Aerospace Designation	Model 7380
Application	Heavy Haul Transport with Passenger Convertiblity
Operating Crew	Commander, Navigator/Radio Operator
Capacity	Up to 25 tons (22.7 Tonnes) (50,000 lb) (22,680 kg)

Additional crew members such as stewards and deckhands may be added depending on the mission requirements.

PERFORMANCE

Maximum calm water speed	50 knots (57.5 mph) (92.5 km/hr)
Continuous gradient capability from standing start	8%
Vertical obstacle clearance	4 ft (1.2 m)
Ditch crossing (width)	10 ft (3.0 m)
Maximum range	550 nautical miles (633 statute miles)

Operable in waves up to at least 6 ft (1.8 m) high

DIMENSIONS

General:

Length, overall	64.8 ft (19.8 m)
Beam, overall	36.7 ft (11.2 m)
Height, overall (on cushion)	22.0 ft (6.7 m)
Height, overall (off cushion)	18 ft 10 inches (5.74 m)
Height of cargo deck (off cushion)	46 inches (1.17 m)
Skirt height, nominal	4.0 ft (1.22 m)
Cushion area	1789 sq ft (166 sq m)
Cushion loading at 88,000 lb	49.2 lb/sq ft (240 kg/sq m)
Buoyancy reserve at 88,000 lb	169%

Cargo Deck:

Length	40 ft (12.2 m)
Width	33 ft (10.1 m)
Cargo Deck height (off cushion)	3.9 ft (1.2 m)
Tiedowns	4 rows, 8.7 ft (2.7 m) apart and at 2.8 ft (0.9 m) longitudinal spacing
Individual tiedown capacity	10,000 lb (4536 kg)

Extra-long items up to the craft length may be stowed on the center module and under the control cab.

WEIGHTS

Weight empty	35,720 lb (16,202 kg)
Maximum permissible gross weight	90,000 lb (40,823 kg)
Design gross weight	78,000 lb (35,381 kg)

POWER MODULES

Engines	Two United Aircraft of Canada/Pratt & Whitney ST6T-75 Marine Gas Turbine Maximum continuous power 1300 shp Maximum permissible power 1700 shp Limiting rpm 6300 - normal operation in 90-95% range
Transmission (2)	Speco, integrated drive for lift fan and propeller
Propellers (2)	Hamilton Standard, Model 43D50, three-bladed 9 ft (2.75 m) dia., controlled pitch
Lift Fan (2)	Bell/BHC 7 ft (2.14 m) dia., twelve-bladed, fixed pitch, centrifugal
Flexible Trunks	4 ft (1.22 m) combination type with 50% fingers

FUEL SYSTEM

Type	Standard aviation kerosene, Jet A, JP4 or JP5
Tanks	Two forward x 330 Imp. gal, six in groups of three x 330 Imp. gal and 3 aft x 220 Imp. gal. Equipped for pressure or gravity refueling.
Capacity	3,300 Imp. gal (3,963 U.S. gal) (15,000 liters)
Boost Pumps	Submerged centrifugal type 24,000 ppH at 5 psi and -40°F

ELECTRICAL SYSTEM

Generators (4)	Gearbox driven brushless, supply 28 volts, D.C.
Batteries (2)	Nickel-Cadmium, 28 volt
External Power	28 volts D.C.

The data which are presented in Table 2-2 reflect the basic Voyageur configuration with a 50 000 lb. payload. For the Coast Guard configuration which is studied herein, the fuel load is increased to 45 000 lb., with a payload of approximately 10 400 lb.

III ANALYSIS OF THE WTGB AND ACV CHARACTERISTICS

The assessment of the feasibility of an air cushion vehicle for deployment with the U.S. Coast Guard requires the study of systems which are comparable with respect to some fundamental operating capability. Since the icebreaking requirements represent an important determining factor in the definition of a cutter configuration, it has been established that the ACV configuration to be compared with the WTGB would be a design with similar icebreaking capabilities. Furthermore, it is considered important, if possible, to utilize an existing ACV for the feasibility investigation and comparisons. There are numerous advantages to the use of an existing ACV for this study. It tends to be a known quantity whose performance, operational and cost parameters are reasonably well defined, together with the fact that the non-recurring development costs have been largely amortized. The Voyageur ACV, one of which is currently in operation with the Laurentian District of the Canadian Coast Guard is the most logical candidate ACV for the evaluations of this study.

The initial task is the determination of the icebreaking capability of the WTGB to provide the icebreaking standards which the ACV design is to meet.

Analysis of the WTGB Icebreaking Capability

The Katmai Bay, the first cutter of the WTGB class, was employed in an icebreaking test program during the winter and spring of 1979 to determine the technical parameters and icebreaking capability of the class in both level and brash ice. These tests are reported and analyzed in Ref. 8. The data from this reference will be used to develop the operating envelope of the cutter class for both types of ice conditions. The operating envelope defines the effect of ice type and thickness upon the achievable ship speed and is a clear representation of the operating limits in a specified ice

environment for a given icebreaking system.

Ice Resistance Data Analysis

The ice resistance data from the full scale test program have been reduced by means of a regression analysis in Ref. 8 for the purpose of developing algorithms for the prediction of the ice resistance of the ship. The Katmai Bay is equipped with a bubbler system which has been designed to improve the cutter capability in ice operations. Consequently, resistance data were obtained for the Katmai Bay with the bubbler system off, and also with it operative. The resistance equations from Ref. 8 were reduced to coefficient form, where the resistance coefficient

$$C_R = \frac{R}{\rho_w \, g \, b \, h^2} \qquad (1)$$

The non-dimensionalization of the resistance provides considerable benefits in the understanding, analysis and comparison of the test results.

The following six resistance algorithms were obtained from the results of Ref. 8 for the Katmai Bay, WTGB class, characteristics.

<u>Level Ice</u> No Bubbler System

$$C_R = 61.3 \frac{\rho_\Delta}{\rho_w} + .0206 \frac{\sigma}{\rho_w g \, h} \frac{V}{\sqrt{g \, h}} \qquad (2)$$

With Bubbler System

$$C_R = 51.3 \frac{\rho_\Delta}{\rho_w} + .0228 \frac{\sigma}{\rho_w g \, h} \frac{V}{\sqrt{g \, h}} \qquad (3)$$

<u>Brash Ice</u> No Bubbler System
h = 1.5 ft.

$$C_R = .133 \frac{\rho_\Delta}{\rho_w} + .0682 \frac{\rho_i}{\rho_w} \frac{V^2}{g \, h} \frac{1}{h} \left(\frac{h}{b}\right)^{.65} \qquad (4)$$

With Bubbler System

$$C_R = .621 \frac{\rho_\Delta}{\rho_w} + .0603 \frac{\rho_i}{\rho_w} \frac{V^2}{g \, h} \frac{1}{h} \left(\frac{h}{b}\right)^{.65} \qquad (5)$$

Brash Ice $\quad$ No Bubbler System

h - 4.0 ft.

$$C_R = 4.84 \frac{\rho_s}{\rho_w} + .0366 \frac{\rho_i}{\rho_w} \frac{V^2}{g\,h} \frac{l}{h} \left(\frac{h}{b}\right)^{.65} \quad (6)$$

With Bubbler System

$$C_R = 4.40 \frac{\rho_s}{\rho_w} + .0305 \frac{\rho_i}{\rho_w} \frac{V^2}{g\,h} \frac{l}{h} \left(\frac{h}{b}\right)^{.65} \quad (7)$$

The resistance equations 4 thru 7 for the brash ice may be rewritten for the WTGB class cutters where

l = 130 ft. at the waterline

b = 34.2 ft. at the waterline

$$\rho_i = 0.9\,\rho_w$$

The resistance equations in brash ice become, for the WTGB,

Brash Ice h = 1.5 ft.	No Bubbler System	$R = 63.7 + 65.3\,V^2$	(8)
	With Bubbler System	$R = 298 + 57.8\,V^2$	(9)
Brash Ice h = 4.0 ft.	No Bubbler System	$R = 16\,511 + 60.75\,V^2$	(10)
	With Bubbler System	$R = 15\,013 + 55.23\,V^2$	(11)

The resistance values which are calculated by Eqs. 8 thru 11 are in pounds, and the velocity is in ft/sec.

Ship Thrust Data

The available thrust for the WTGB class cutters may be determined from the data which appear in Ref. 8. The cutters of the class utilize a single

screw with a diameter of 8.5 ft., and the propulsive power level is 2 500 horsepower. The open water characteristics of the propeller have been presented in Ref. 8 and are reproduced herein as Fig. 3-1. Model testing of the propeller installation has yielded a hull efficiency of 1.08, where the hull efficiency is given as the ratio of the effective horsepower, EHP, to the thrust horsepower, THP. Also,

$$\frac{EHP}{THP} = \frac{1 - t}{1 - w} = 1.08 \qquad (12)$$

where t is the thrust deduction factor, $1 - R/T$

w is the wake factor, $1 - V_a/V$, and V_a is the velocity seen by the propeller.

In the analysis of Ref. 8, a thrust deduction factor of 0.2 was recommended and that factor has been employed herein. Using the open water propeller data of Fig. 3-1, and the hull efficiency and thrust deduction factors which have been identified above, the effective thrust - speed relations for the WTGB class cutters may be determined for various propulsive power levels, as shown in Fig. 3-2. This information also permits the propulsive coefficient variation with ship speed and horsepower to be found. The propulsive coefficient is an overall propulsion system efficiency, and is calculated as

$$P.C. = \frac{R\,V}{550\ HP} \qquad (13)$$

The variation of the propulsive coefficient with ship speed and horsepower for the WTGB class is presented in Fig. 3-7.

WTGB Performance Estimates

The resistance and thrust characteristics of the WTGB class of cutters which have been discussed previously may be combined to determine the per-

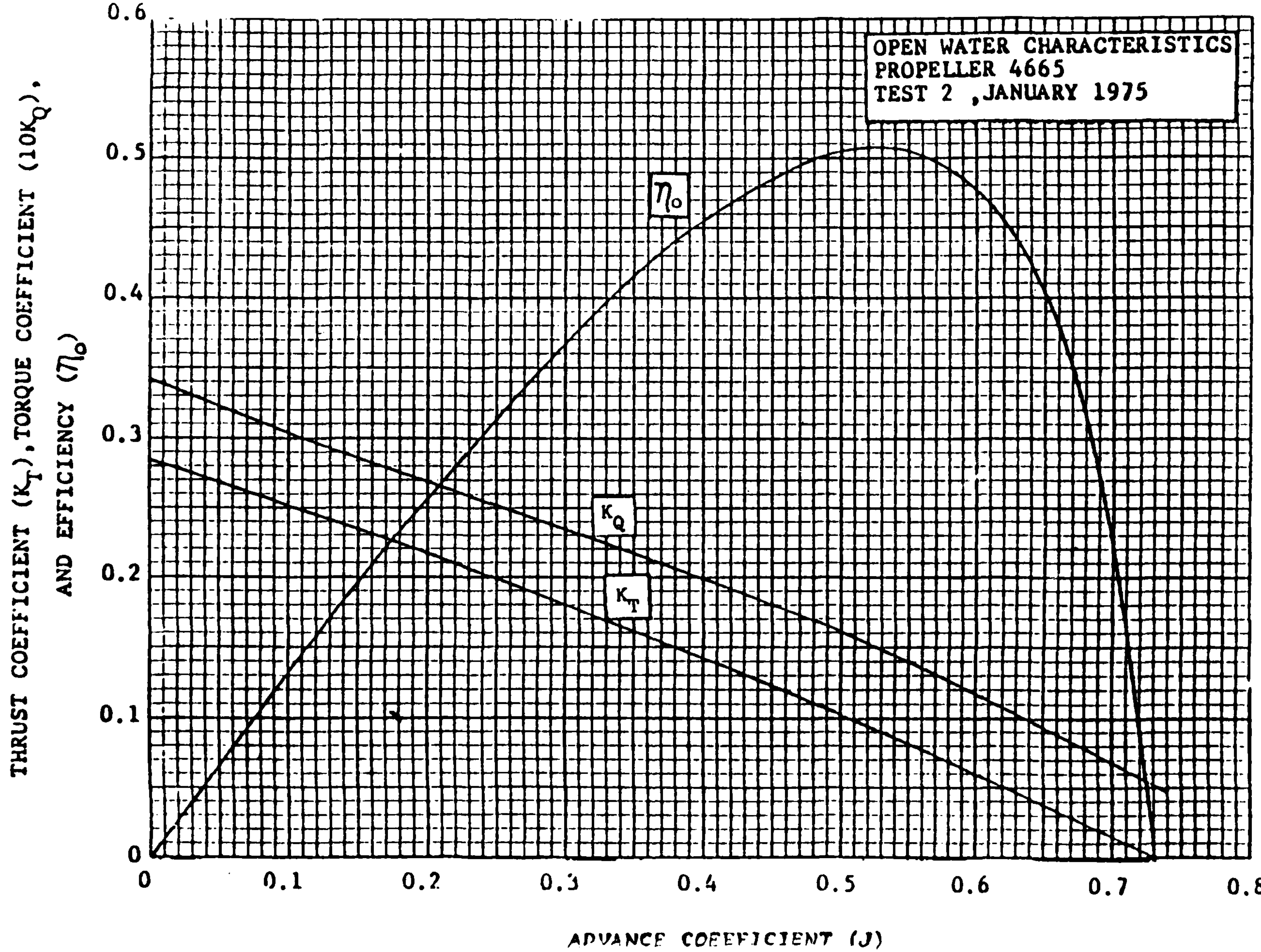

OPEN WATER CHARACTERISTICS
PROPELLER 4665
TEST 2 ,JANUARY 1975
η_o
K_Q
K_T
THRUST COEFFICIENT (K_T), TORQUE COEFFICIENT ($10K_Q$), AND EFFICIENCY (η_o)
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
ADVANCE COEFFICIENT (J)

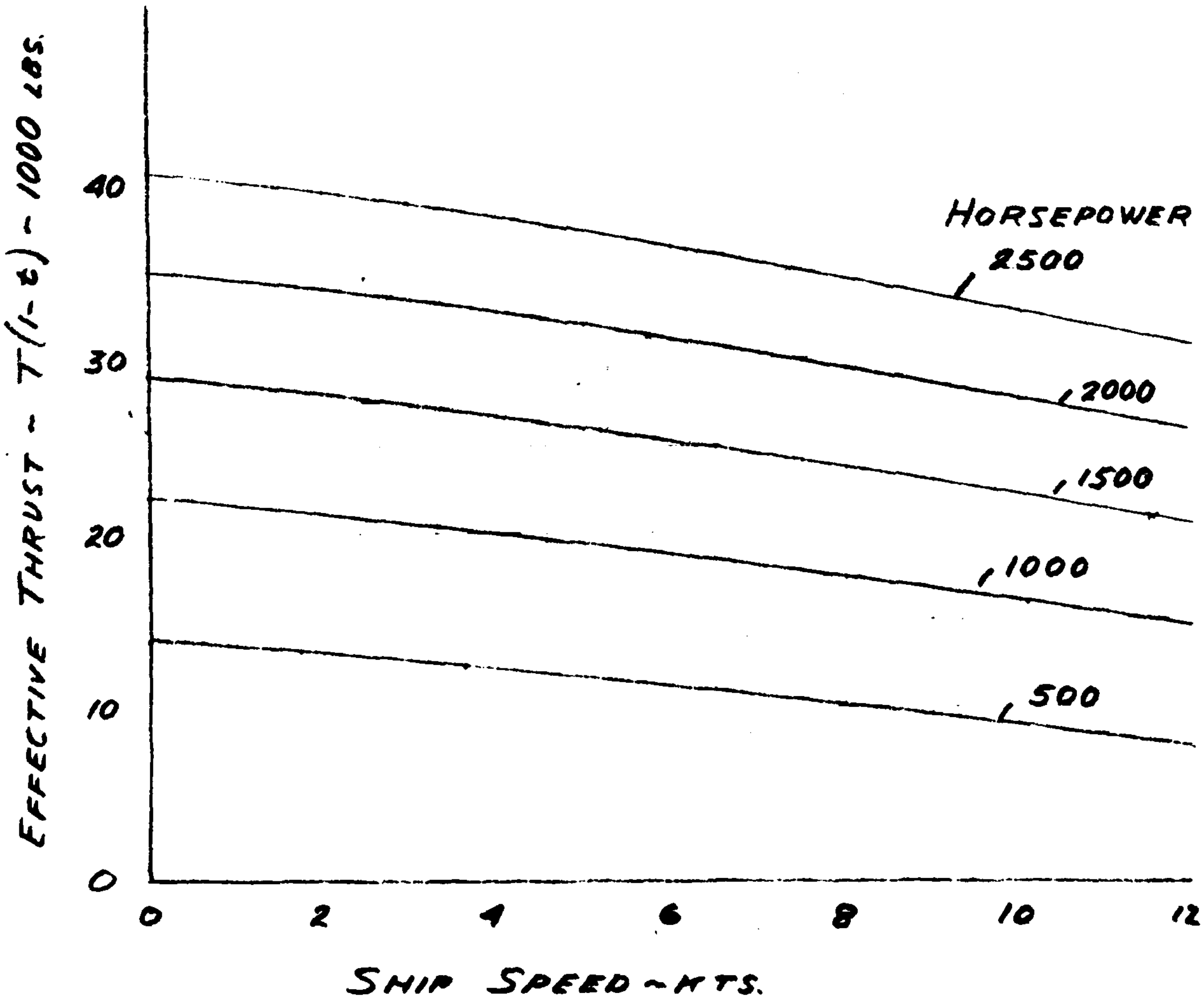
FIG. 5-1

FIG. 3-2

VARIATION OF EFFECTIVE THRUST WITH SHIP SPEED FOR THE U.S. COAST GUARD CUTTERS OF THE WTGB CLASS

$t = 0.2$

SEE NOTE A, PG. 17



Note A

Following the completion of the WTGB thrust analysis shown in Fig. 3-2, the results of full scale static bollard pull tests on the Katmai Bay became available. At the maximum horsepower rating of 2 500 HP, the following data are applicable:

Full Scale Static Test Results	Bollard Pull	55 500 lbs.
	Propeller Thrust	55 500 lbs.
	Thrust Deduction Factor	0
Model Propeller - Open Water Tests	Propeller Thrust using Fig. 3-1	51 100 lbs.

There are two main unexpected results from the above tabulation:

(1) the full scale static tests indicate the thrust deduction factor to be zero in the static condition.

(2) the bollard pull is 8.6 % greater than the static thrust which is predicted from the open water tests of the model propeller.

The previous model tests of the WTGB which were conducted by the David Taylor NSRDC have led to the recommendation of a thrust deduction factor of 0.2 (See Ref. 8) for the open water operations of the cutter. The thrust predictions of Fig. 3-2 have been made with a thrust deduction factor of 0.2 which correlates well with the open water performance of the WTGB. At the present time, the anomalies between the bollard pull full scale tests and the previous data have not been adequately explained. Conceivably, the differences could be related to the temperature effects upon the calibrations of the instrumentation which was employed in the full scale static tests of the Katmai Bay. It has been reported that the instrumentation was calibrated in the laboratory at NSRDC prior to its shipment to Sault Ste. Marie for use with the tests of the Katmai Bay.

formance characteristics of the cutters in an ice environment. Fig. 3-3 shows the case of level ice with and without the bubbler system in operation while Fig. 3-4 presents the comparable data in brash ice. The data of Figs. 3-3 and 3-4 provide the basis of the definition of the operating envelope in level ice as shown in Fig. 3-5 and the operating envelope in brash ice as shown in Fig. 3-6.

Fig. 3-5 indicates that the level icebreaking capability of the WTGB is increased from 1.75 feet (21 inches) to 1.93 feet (23 inches) thru the operation of the bubbler system. However, the benefits of the bubbler system in the reduction of the propulsive power requirements disappear when the cutter speed reaches 6 knots, a steady state speed at which 1.1 feet of level ice may be broken. In order to break 1.93 feet of level ice, without the bubbler, it is estimated that 850 additional horsepower must be supplied to the ship propeller. This estimate is made with the recognition that the level ice resistance under static conditions will vary as the square of the ice thickness, and the propeller static thrust varies as the 2/3 power of the power input to the propeller. Consequently, the propulsive horsepower requirement to break the level ice sheet is proportional to the cube of the ice sheet thickness. In Ref. 8, the bubbler system power requirement is given as 200 HP, so that the net gain from the bubbler system is approximately 650 HP in the limiting zero speed point of the operating envelope.

In summary, it would appear that the bubbler system operation offers some gains in cutter efficiency when the level ice thickness is increased above 1.2 feet, and the use of the bubbler is less efficient at lesser values of the level ice sheet thickness.

In a brash ice environment, with the brash ice thicknesses up to the four foot range of the resistance correlations, the WTGB is able to maintain speed in excess of 9 knots, with and without the operation of the bubbler system, as shown in Fig. 3-6. It appears that the bubbler system is

FIG. 3-3

RESISTANCE AND THRUST VARIATION WITH SPEED FOR THE WTGB CLASS CUTTER IN LEVEL ICE

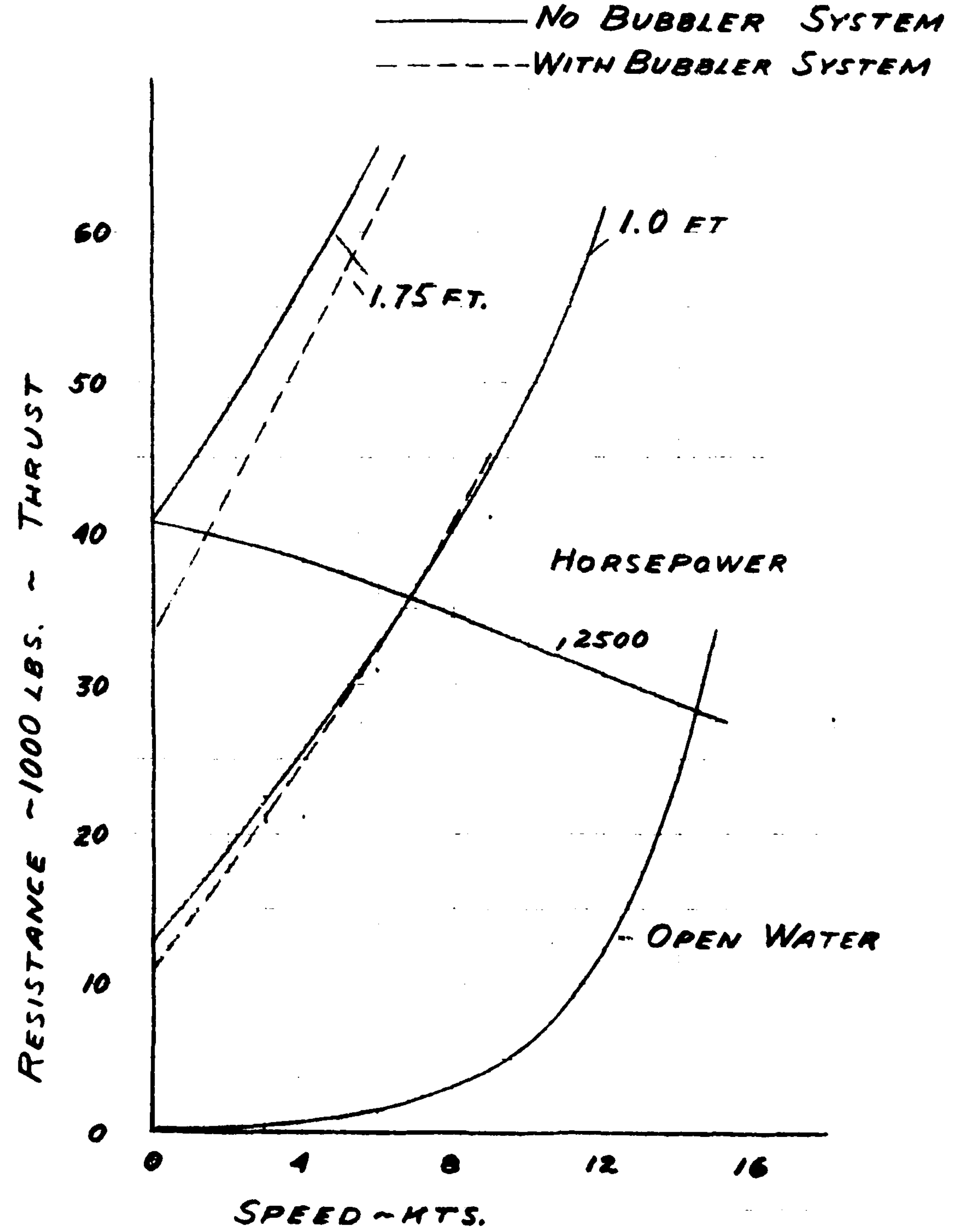


FIG. 3-4

RESISTANCE AND THRUST VARIATION WITH SPEED FOR THE WTGB CLASS CUTTER IN BRASH ICE

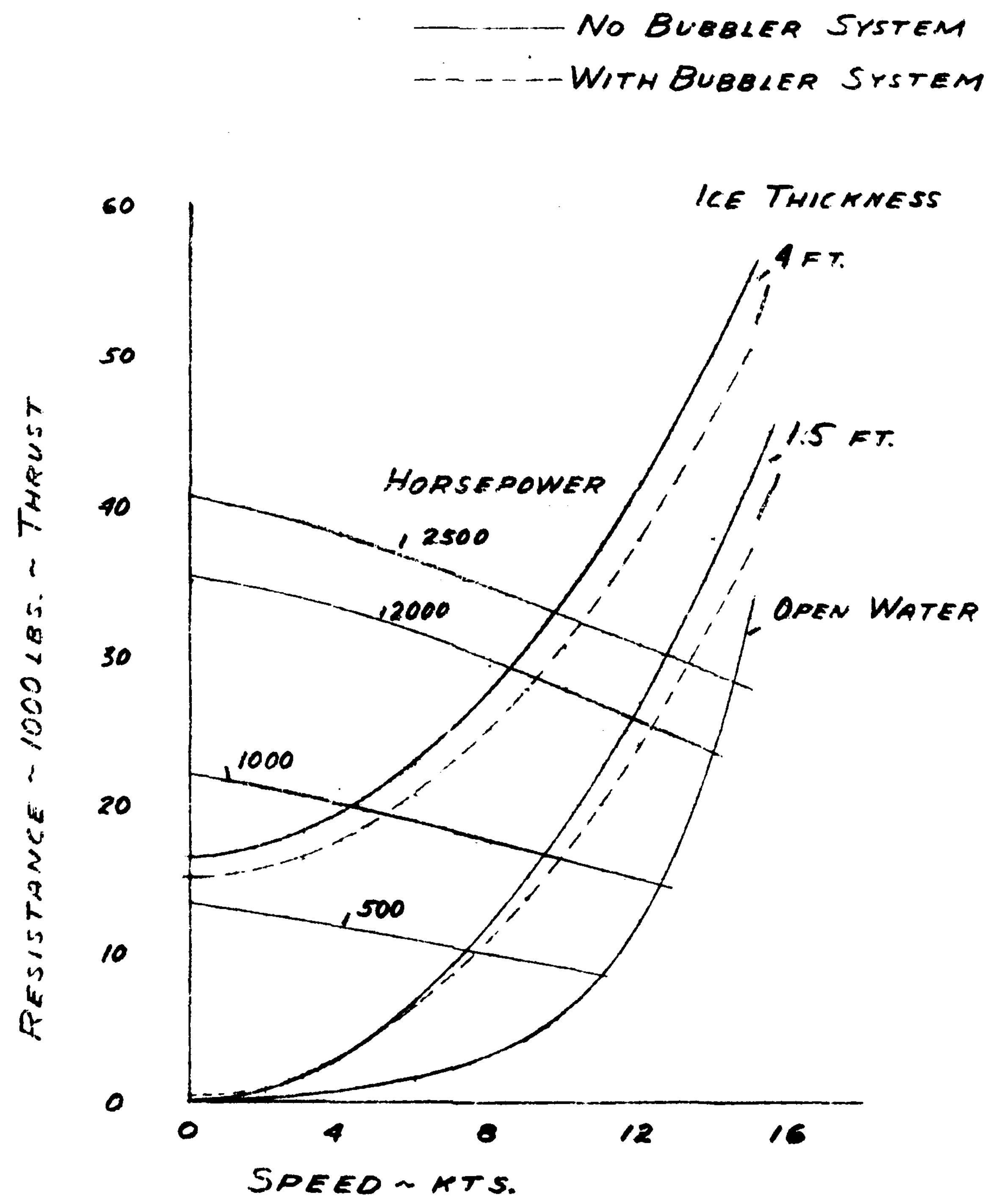


FIG. 3-5

OPERATING ENVELOPE IN LEVEL ICE OF THE U.S. COAST GUARD CUTTERS OF THE WTGB CLASS

HP = 2500

FROM FULL SCALE TEST RESULTS AS SHOWN IN FIG. 3-3

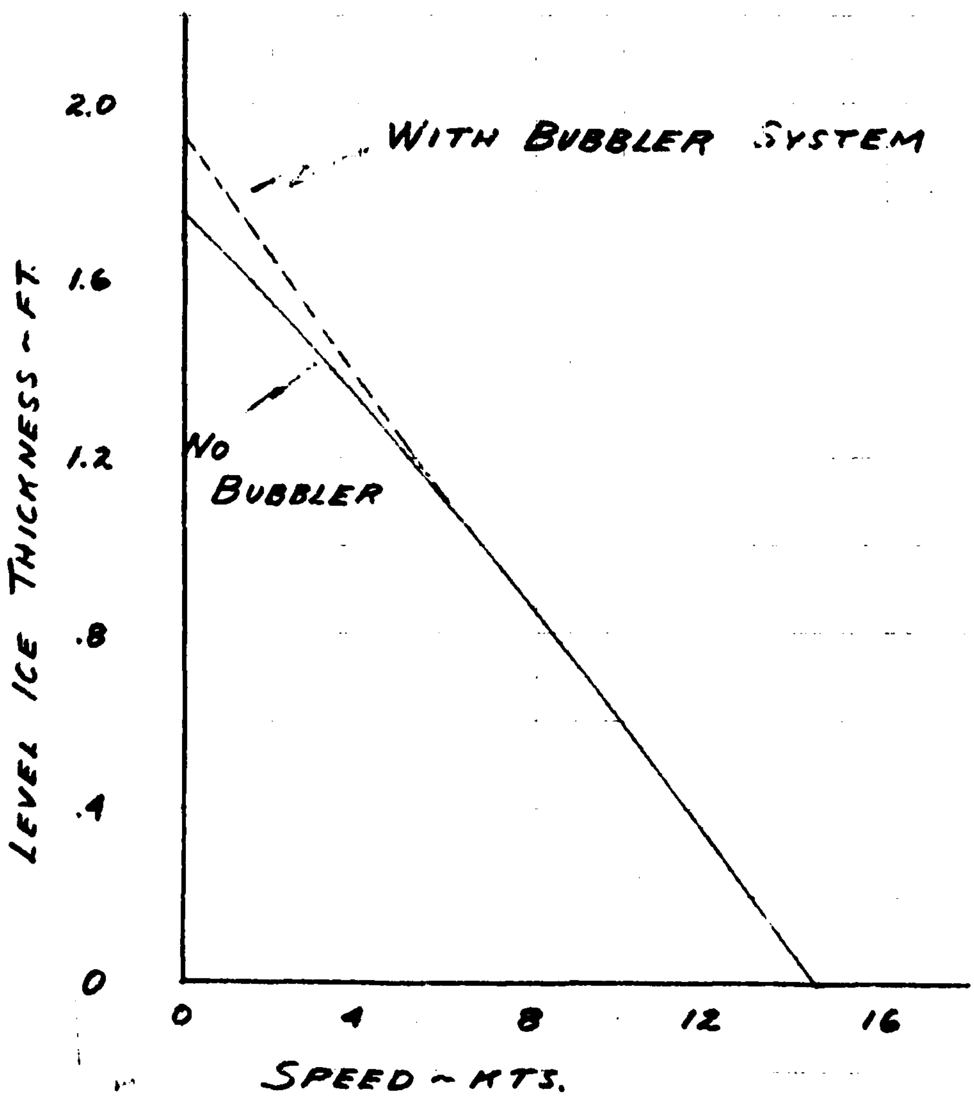
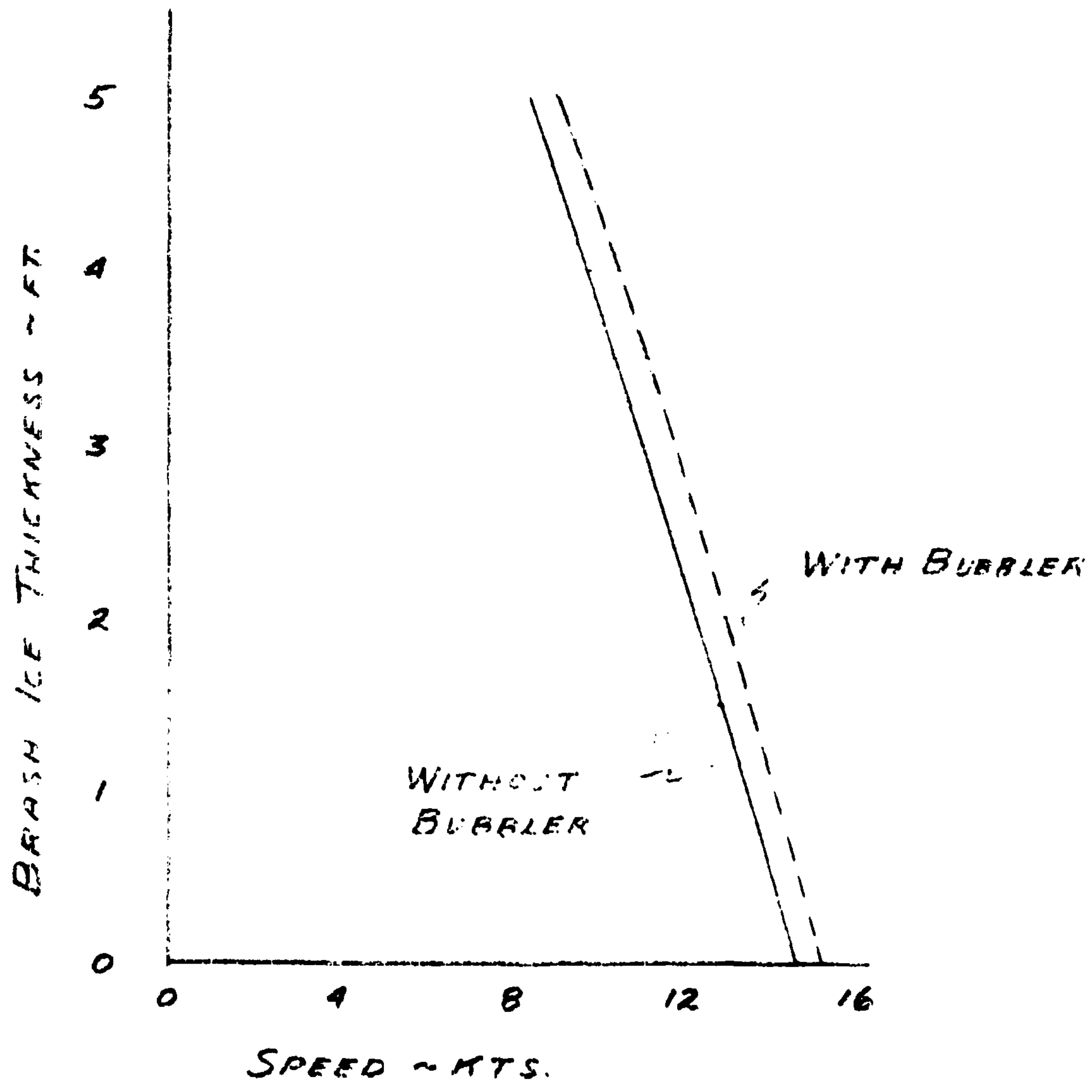


FIG. 3-6

OPERATING ENVELOPE IN BRASH ICE OF THE U.S. COAST GUARD CUTTERS OF THE WTGB CLASS

HP = 2500

FROM FULL SCALE TEST RESULTS



capable of increasing the speed of the WTGB in brash ice by approximately 0.7 knots over the range of brash ice thicknesses which were tested. As an approximation, the application of the 200 horsepower to the propeller would produce similar speed increments to the ship.

The propulsive coefficient (overall propulsive system efficiency) is substantially influenced by the power requirement variation at a given speed as the ice environment is altered. The variation of the propulsive coefficient with speed for several operating conditions without the bubbler system in operation is shown in Fig. 3-7 in conjunction with the propulsive coefficient variation with speed at several horsepower values. The conditions which are shown include:

(a) Open water
(b) 1.5 ft. thick brash ice
(c) 4.0 ft. thick brash ice
(d) 1.0 ft. thick level ice

The open water variation of the propulsive coefficient ranges from 58 % at a speed of 7 kts. to 50.5 % at the maximum speed of 14.7 kts. In 1.5 foot thick brash ice, the propulsive coefficient peaks near 48 % in the speed range near 10 kts. When the brash ice thickness is increased to 4.0 feet, the peak propulsive coefficient of 40 % is reached at the maximum achievable speed of 9.7 kts. In level ice, of a 1.0 foot thickness, the peak propulsive coefficient of 30 % is achieved at the maximum speed of 6.9 knots.

From these data and an examination of Fig. 3-7, it is apparent that an increasing severity in the ice environment, requiring increased propulsive horsepower at a given speed, leads to reductions in the propulsive coefficient over the entire speed range. The fact that increases in ship resistance lead to more highly loaded propeller operating conditions with lower values of ideal efficiency explains the predicted and observed test variations of the pro-

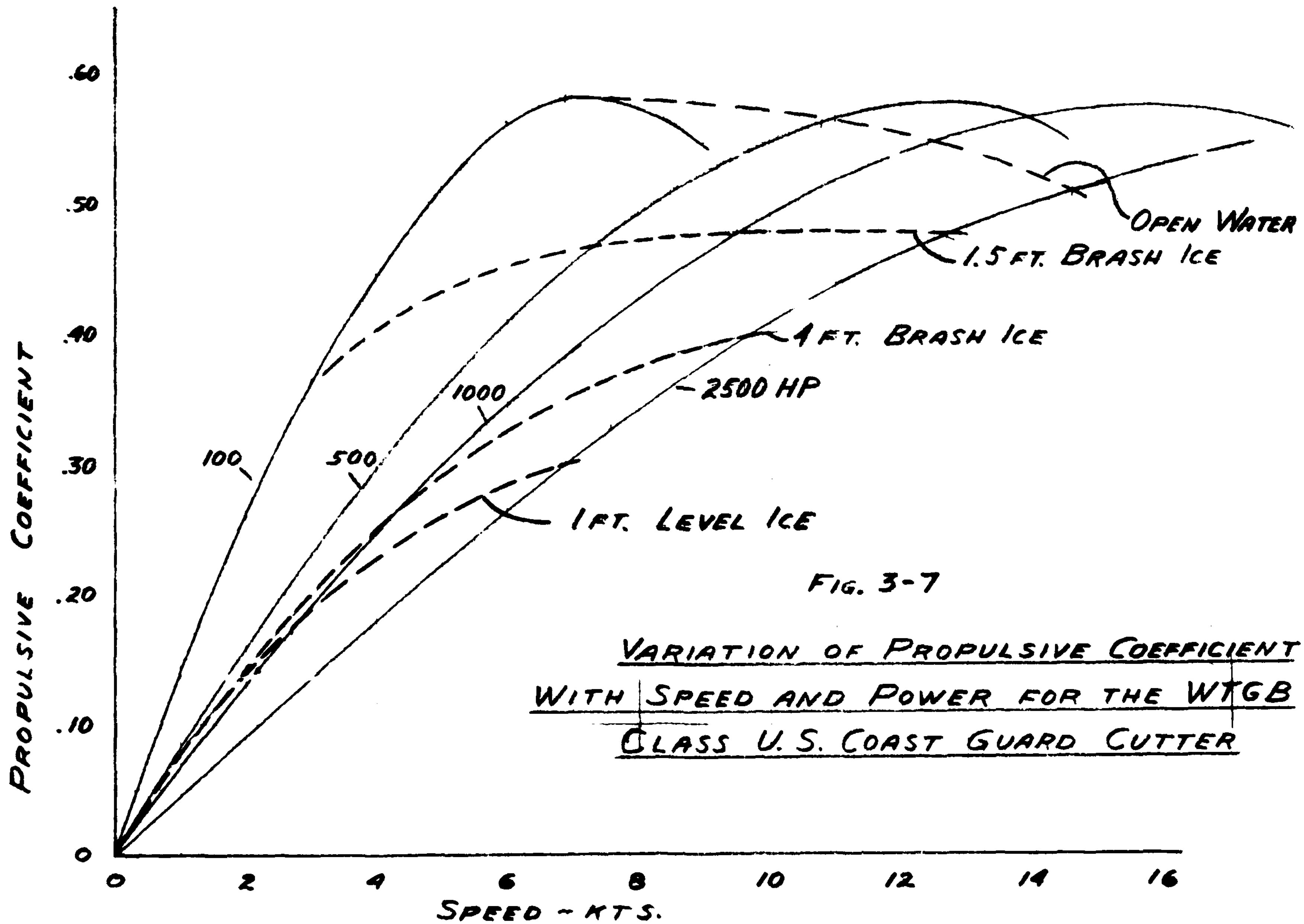


FIG. 3-7

VARIATION OF PROPULSIVE COEFFICIENT WITH SPEED AND POWER FOR THE WTGB CLASS U.S. COAST GUARD CUTTER

pulsive coefficient. The effect of the ice conditions upon the cutter propeller performance, at a given speed and horsepower level, appears to be minimal for the WTGB configuration.

Air Cushion Vehicle Design Study

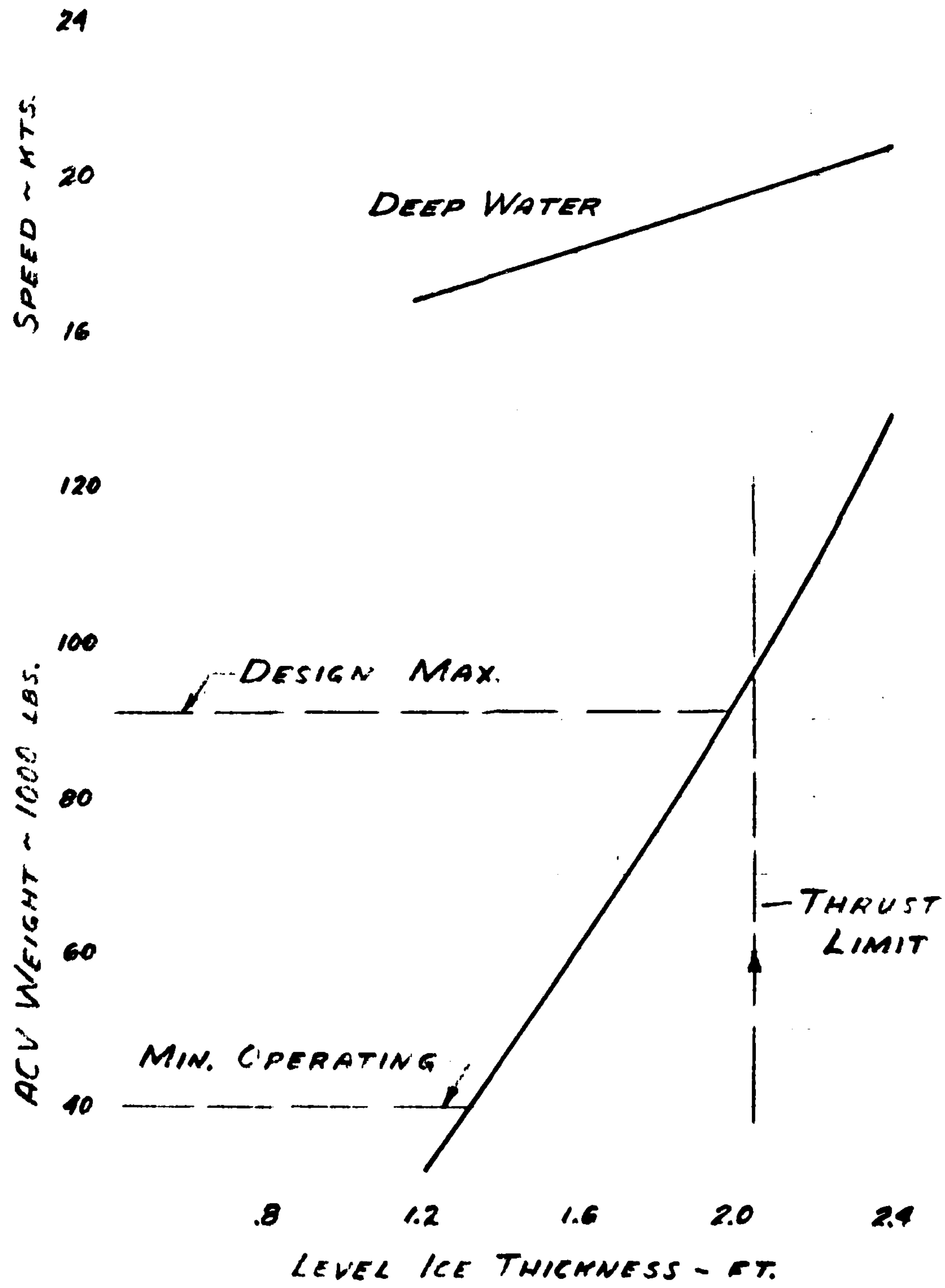
In order to develop a meaningful comparison between the WTGB class of cutters with an ACV which is designed with similar capabilities, it is of importance that the ACV and the WTGB possess equivalent ability in the breaking of level ice. It has been determined from the analysis of the WTGB full scale icebreaking test data that the cutter with the bubbler system in operation can break 1.93 feet of level ice with a flexural strength of 14 400 psf.

In view of the fact that the use of an existing ACV configuration would be expected to provide substantial cost benefits, the Voyageur capability has first been evaluated by the methods of Ref. 6 to define its operating envelope in level ice. The results of these calculations are shown in Fig. 3-8. At its design gross weight of 91 000 pounds, the Voyageur is capable of breaking 2.0 feet of level ice at a speed of 19.3 knots. The predicted width of the broken ice track is 117 feet. At its minimum operating weight of 40 000 pounds, the Voyageur can break 1.3 feet of level ice at a speed of 17.2 knots, with a broken ice track width of 112 feet. Fig. 3-9 shows the Canadian Coast Guard Voyageur in a pirouette turning maneuver at the end of an icebreaking run in 25 inches of ice. It should be noted, at this point, that ice which is either more brittle, or of reduced flexural strength is more easily broken by an ACV icebreaker. Consequently, in some cases the Voyageur will break ice of a greater thickness than the predicted value of 2.0 feet.

The WTGB class bubbler system in operation capability is matched at a Voyageur weight of 86 000 pounds. On the basis of these comparisons, it

Fig. 3-8

Operating Envelope in Level Ice for the Voyageur ACV

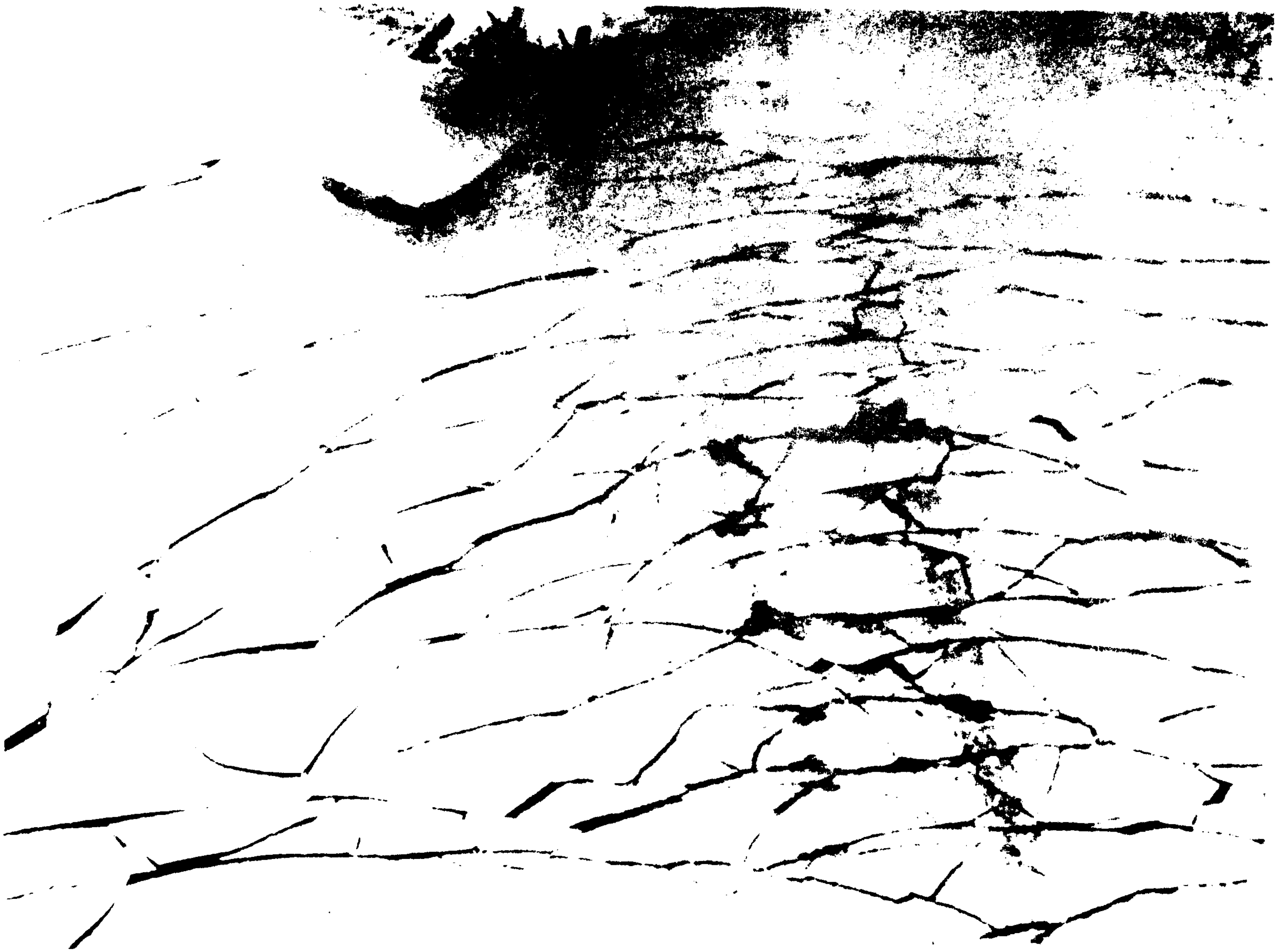


appears that the Voyageur and the [illegible] have comparable capabilities in the breaking of level ice. Consequently, the comparative ACV and displacement hull cutter evaluations may be conducted between the Voyageur and [illegible].

The maximum capability of an ACV to conduct an icebreaking operation may be limited by either the vehicle weight or by the thrust which is available from the propulsion system. In the case of the Voyageur, the thrust level at a power setting of 1 300 HP per nacelle is capable of providing sufficient thrust to break 2.05 feet of level ice, at a vehicle weight of 86 000 pounds as shown in Fig. 3-8.

The variation with speed of the thrust at normal rated power and the vehicle resistance for the Voyageur in operation at 86 000 pounds gross weight over an ice sheet of 1.63 feet thickness is shown in Fig. 3-10. With a power rating of 1 300 HP for each of the two ST6T-75 engines, a maximum speed of 52.3 knots over the ice sheet may be achieved. The peak resistance occurs at the resonant speed of 19.3 knots in the high speed icebreaking condition. At higher speeds, the resistance which results from ice sheet deformation is reduced inversely as the fourth power of the speed, and the ice sheet does not fracture at speeds which are appreciably above that for resonance. At the icebreaking speed of 19.3 knots, the available thrust margin is approximately 600 pounds at a total horsepower level of 2 600 HP.

The analysis of the Voyageur ACV thus far has been predicated upon the craft operation as an icebreaker in waters of a depth of [illegible] feet or more. Under these conditions, the ice is supported by "deep water" from an analytical point of view. The water depth is important to ACV icebreaking, since it has a substantial effect upon the resonant speed for high speed ACV icebreaking operations. The resonant speed is reduced significantly in shallow water, although the other aspects of the ACV icebreaking action are unchanged. The influence of water depth will be examined in the comparison of the [illegible] and ACV which is the subject of the following discussion.



Bell Aerospace Canada textron 332859-33

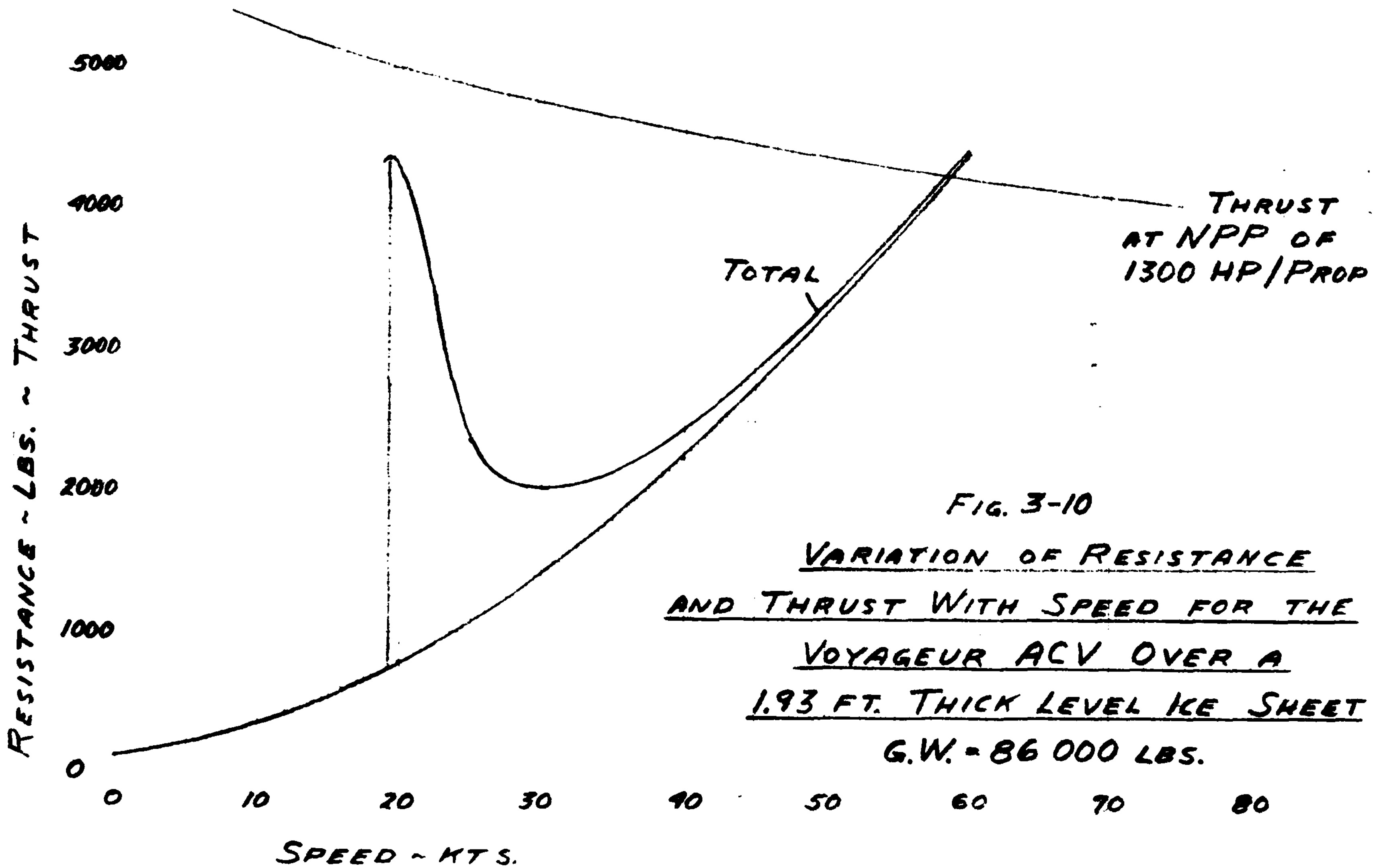


Fig. 3-10

Variation of Resistance and Thrust With Speed for the Voyageur ACV Over a 1.93 ft. Thick Level Ice Sheet

G.W. = 86 000 lbs.

Range and Fuel Consumption Comparisons of the WTGB and Voyageur ACV

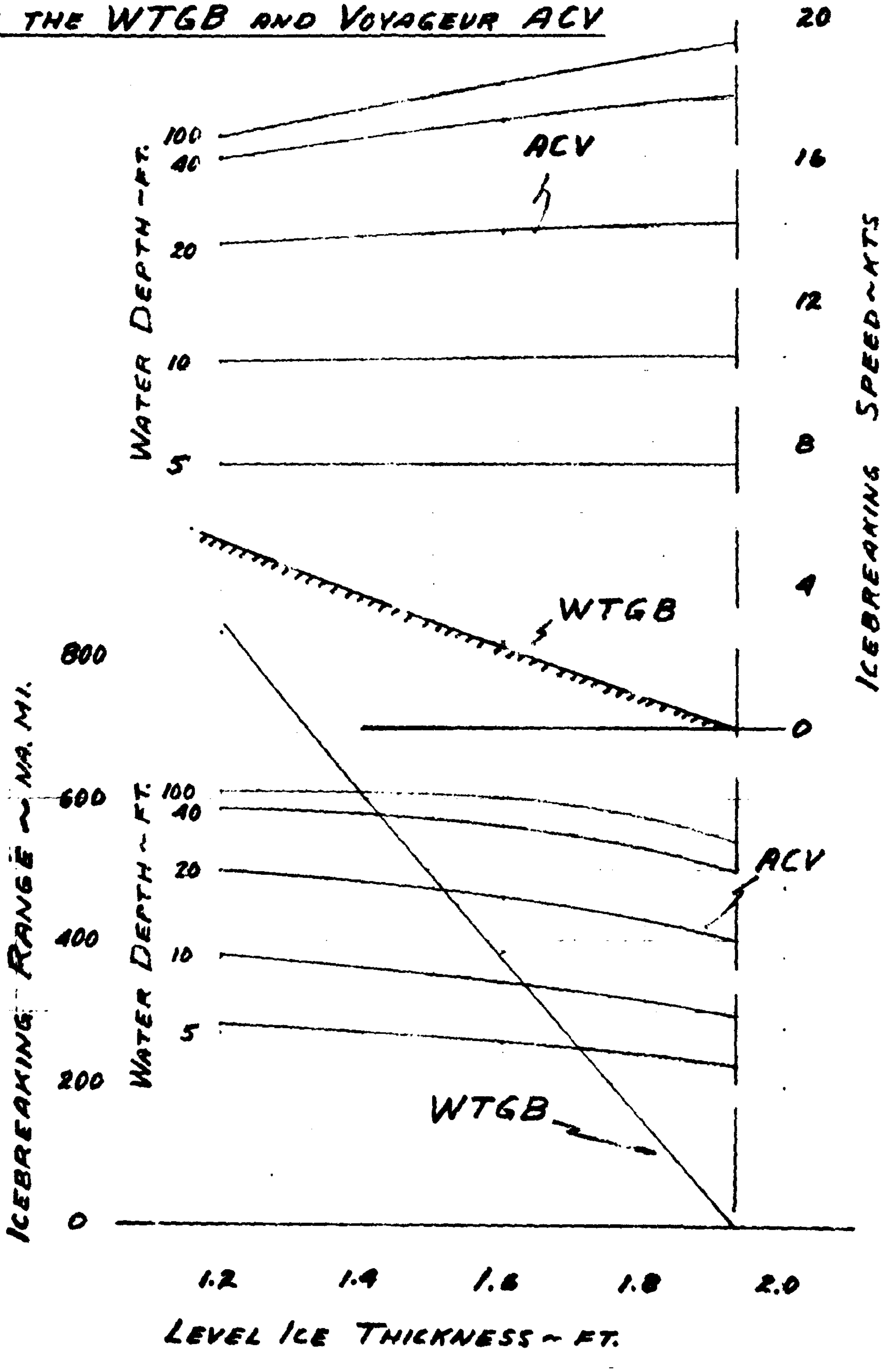
It is of some significance to compare the range and fuel consumption characteristics of the WTGB and the Voyageur ACV in operations over level ice. The WTGB main engines develop 2 500 HP and its air bubbler system requires 200 HP. The normal power rating of the Voyageur totals 2 600 HP. It is apparent that the installed power levels of the two vehicles are comparable, despite the 662 ton displacement of the WTGB and 41 ton displacement of the Voyageur. The respective fuel loads are 160 000 and 45 000 pounds.

In the case of the displacement hull icebreaker configurations, the high resistance which is experienced at zero speed from the requirement to break the ice sheet leads to most efficient operation at the maximum continuous power rating. The variation of maximum range (without margin) with level ice thickness for the WTGB is shown in Fig. 3-11. The figure also includes the variation of the icebreaking speed of the WTGB with the level ice thickness. Both of those parameters go to zero at a level ice thickness of 1.93 feet, which is the limiting ice thickness for continuous motion of the WTGB. At zero ice thickness (open water), the maximum range of the WTGB is 4 000 na. mi. at a speed of 12 knots. It is also evident that both the icebreaking speed and range of the WTGB increase in approximately a linear manner as the level ice thickness is reduced. A range of 830 na. mi., obtained at a speed of 5.2 knots is available at a level ice thickness of 1.2 feet.

The speed for high speed icebreaking with the Voyageur ACV is influenced substantially by the water depth beneath the ice sheet, and to a lesser extent by the level ice thickness as is also shown in Fig. 3-11. The ACV is able to break ice without restrictions as to water depth, while the WTGB draft of 12 feet limits its icebreaking operations to waters which are deeper than 12 feet.

At a water depth of 5 feet, the Voyageur breaks ice at a speed of 7.4

FIG. 3-11
COMPARISON OF THE ICEBREAKING PERFORMANCE OF THE WTGB AND VOYAGEUR ACV



knots over the entire range of level ice thicknesses which may be broken by the craft. At this water depth, it is not possible to propagate the underwater wave at higher speeds to achieve an increased resonant speed. The icebreaking speed increases rapidly with water depth, and as the water depth approaches 60 feet, the "deep water" condition is essentially reached. The icebreaking speed in deep water varies from 16 to 19 knots as the ice thickness is increased from 1.2 to 1.93 feet.

The icebreaking range of the Voyageur is reduced in shallow water operating conditions. In "deep water" the Voyageur icebreaking range varies from 600 na. mi. to 525 na. mi. as the level ice thickness increases from 1.2 to 1.93 feet. At a water depth of 5 feet, the comparable range variation is from 280 na. mi. to 225 na. mi. The ACV icebreaker range is far less sensitive to level ice thickness than is a conventional displacement hull icebreaker.

The fuel consumption of an icebreaker in breaking a stretch of ice is an important measure of its overall efficiency. Fig. 3-12 compares the fuel usage in pounds per nautical mile of the WTGB and the Voyageur ACV over a range of level ice thicknesses from 1.2 feet to 1.93 feet. The WTGB class cutter fuel usage does not vary with the water depth, while that of the Voyageur is markedly affected by the depth of water beneath the level ice sheet. Reductions in the water depth lead to increases in the fuel burned by an ACV icebreaker per mile of advance thru the ice sheet, although the hourly fuel consumption itself is somewhat reduced. In all cases, however, the fuel efficiency in icebreaking of the ACV icebreaker is significantly better than that of the WTGB.

Broken Ice Channel Width Considerations

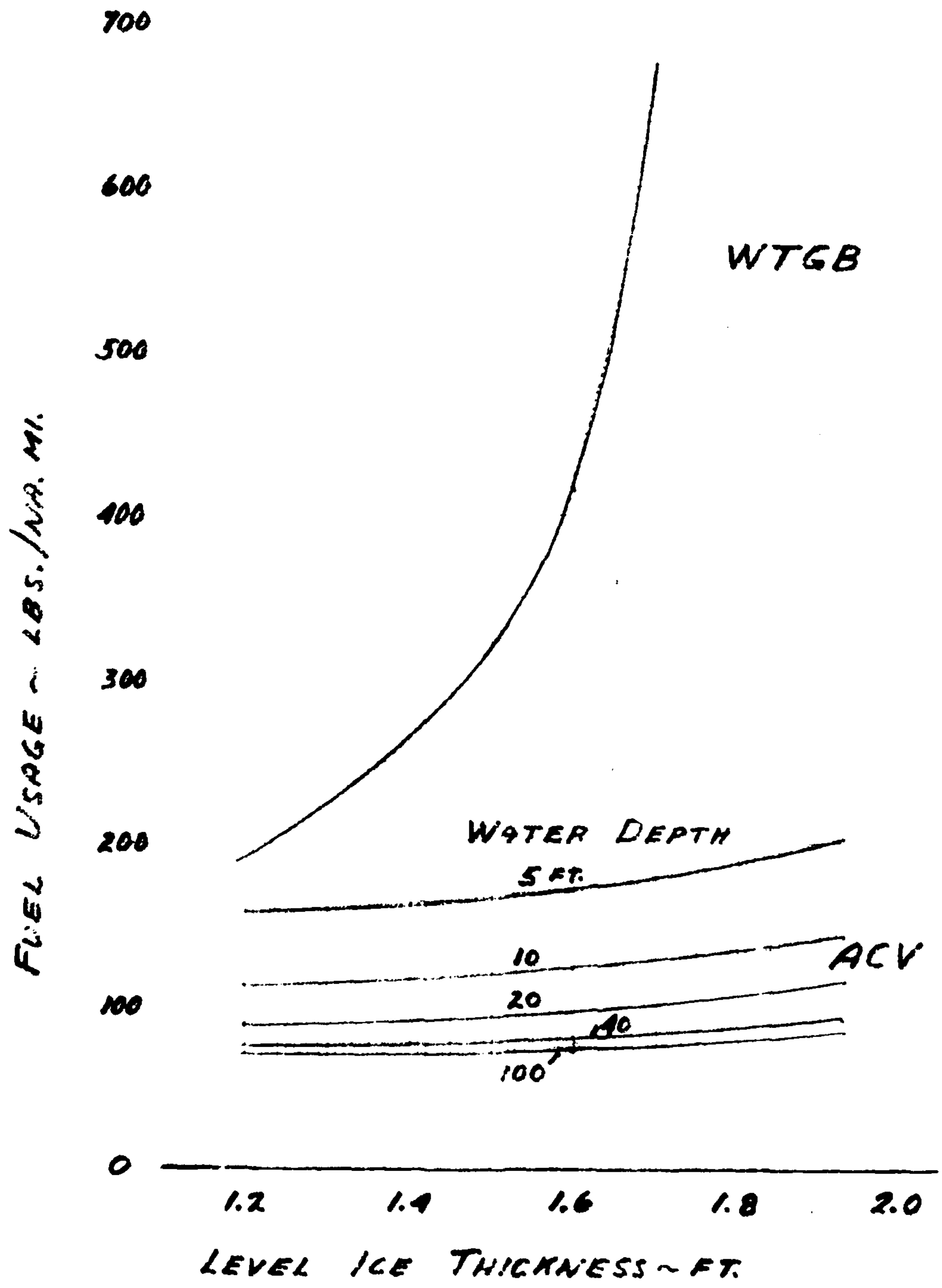
An ACV icebreaker and a conventional icebreaker produce substantially different effects upon a level ice field in their icebreaking operations. A discussion of certain of these effects is pertinent, and will now be addressed.

An ACV icebreaker will break a comparatively wide channel in level ice, and the broken ice will tend to remain in place. Wind or current action may clear the broken ice from this channel. The width of the broken ice channel is a function of the cushion area of the ACV icebreaker, the elastic modulus of the ice, and the ice sheet thickness. In theory, the broken ice channel width varies as the 3/4 power of the ice thickness. The Voyageur, in a 2 foot thick level ice field, produces a channel about 110 feet wide. Repeated passes of the ACV icebreaker over adjacent stretches of ice may be used to widen the broken ice channel, and repeated passes over a previously broken ice channel may be employed to break up further and upset the broken ice pieces. Since the resistance of a displacement ship as it moves thru a broken ice field is markedly reduced by a widening of the broken ice channel, there are some clear advantages which accrue from the widening of a broken ice channel. An increase in the broken ice channel width from 1 ship beam to 2 ship beam widths will result in a 25 % reduction in the low speed ice resistance of the ship.

The effect of the level ice thickness upon the broken ice channel width of a conventional icebreaker is quite different. In ice whose thickness is near the capability of the icebreaker, and the resulting icebreaking speed is low, the conventional icebreaker produces a clear ice channel of a width which approximates the beam of the icebreaker. However, when the ice is substantially less thick than the icebreaker is capable of breaking, its speed capability is increased as is shown in Fig. 3-5. The waves which are generated by the ship motion at the increased speeds are capable of breaking the less thick level ice sheet in their own right. The broken ice channel which is developed in this fashion may extend well beyond the beam of the icebreaker in the athwartship direction.

Fig 3-12

COMPARISON OF THE FUEL EFFICIENCY IN ICEBREAKING OPERATIONS OF THE WTGB AND VOYAGEUR ACV



Analysis of the Primary Voyageur ACV Performance Characteristics

Before it is possible to evaluate the Voyageur ACV against the cutter performance requirements, is is necessary to quantify certain of its performance capabilities. The Voyageur ACV has a maximum weight of 91 000 pounds, and an empty weight of 35 600 pounds. The useful load of 55 400 pounds is available for distribution between payload and fuel. For the comparative evaluations, it has been assumed that a constant weight payload of 10 400 pounds is appropriate, leaving 45 000 pounds for the fuel load. The range and endurance estimates for the Voyageur ACV have been made on this basis.

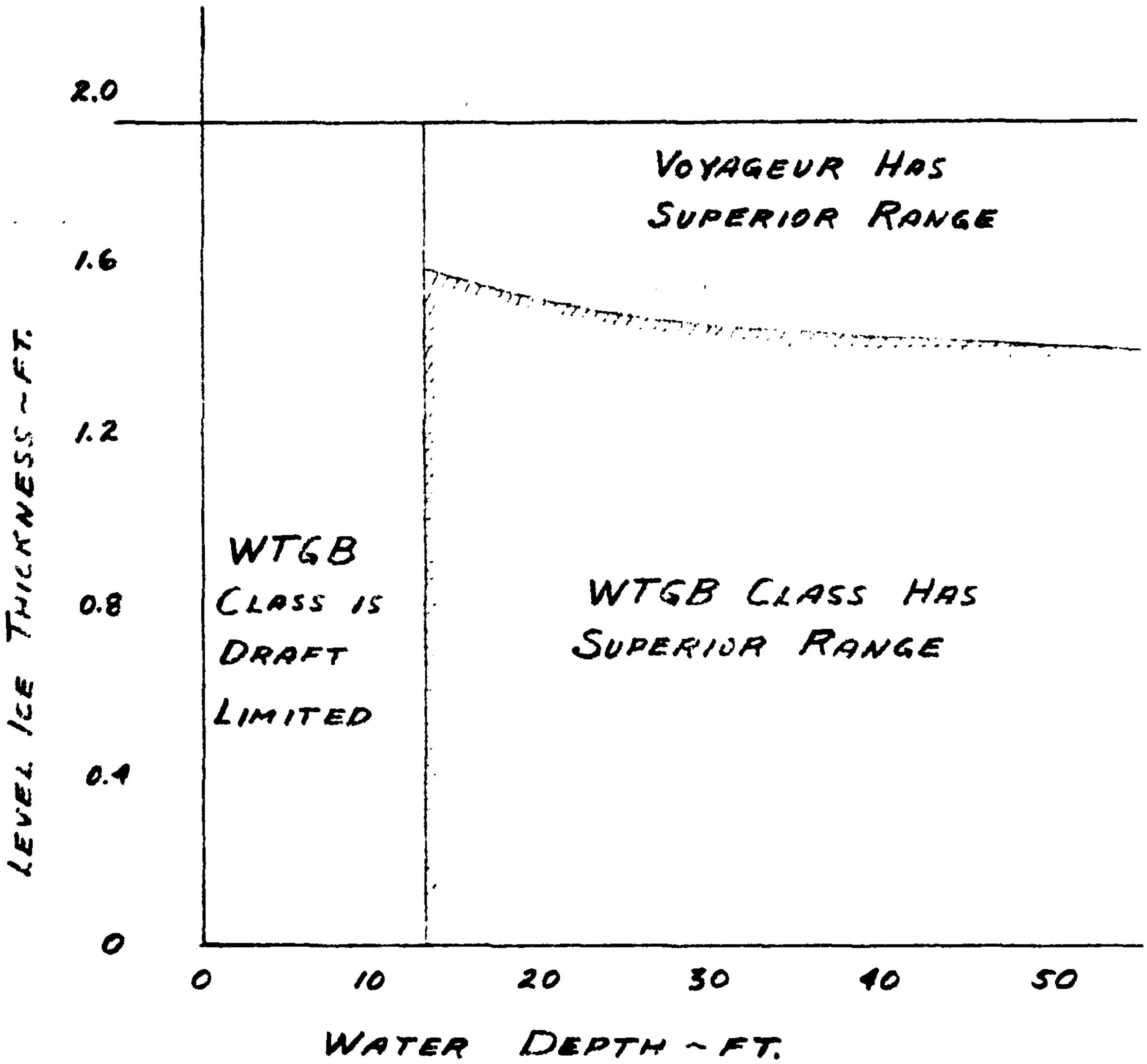
ACV Icebreaking Performance

Fig 3-11 compares the Voyageur ACV and the WTGB class cutters for operations in level ice. The data which are presented in this figure have been utilized to develop an operating environmental boundary which defines the ice thickness and water depth combinations for which each of the two systems possesses equivalent icebreaking range. This operating boundary is shown in Fig.3-13. In water depths of less than 13 feet, the WTGB class cutters cannot operate due to the draft of the vessels. In deeper waters, the WTGB possesses the superior range in icebreaking operations in the cases in which the level ice thickness is less than 1.4 to 1.6 feet, depending upon the water depth. It should be noted, however, that the fuel load of the WTGB is well over three times that of the Voyageur ACV. The gas turbine engines of the Voyageur burn JP-5 fuel, and the WTGB utilizes a marine diesel type of fuel.

The icebreaking range of the Voyageur in shallow water of 13 foot depth is 330 na. mi. at the limiting ice thickness of 1.93 feet. The WTGB is not able to maintain continuous motion thru ice of this thickness, but must back and ram the ice sheet to make headway. It is worthwhile noting that the ACV

FIG. 3-13

OPERATING ENVIRONMENTAL BOUNDARIES FOR ICEBREAKING RANGE SUPERIORITY BETWEEN THE WTGB CLASS AND VOYAGEUR ACV



icebreaker may operate along the open water edge of an ice sheet and break level ice which is approximately 40 % thicker than its capability within the interior of an ice sheet.

Fig. 3-14 provides the icebreaker speed and fuel consumption characteristics of the WTGB class cutters and the Voyageur ACV over the operating range of water depth and level ice thickness. This figure provides a direct comparison between the two types of icebreaker over the range of the operating conditions. The limitations of the WTGB with respect to water depth become evident, and the advantages of the ACV icebreaker with respect to speed and fuel consumption are easily assessed from this chart.

An ACV icebreaker, operating in the high speed mode, leaves a wide track of broken ice, but not a clear, ice free channel. The broken ice channel offers greatly reduced resistance to a following displacement ship. On the other hand, a displacement hull icebreaker initially provides a clear, ice free channel of a width which approximates its beam. It would appear that there may be merit to the employment of ACV and conventional icebreakers, working as a team in areas which are near or beyond the capability of the displacement hull icebreaker. As an example, with a level ice thickness of 1.8 feet, the WTGB icebreaking range is approximately 150 na. mi., covered at a speed of 0.8 knots. The Voyageur breaks this ice at a speed in excess of 16 knots in waters of a depth of 30 feet, and the available range is 500 na. mi.

Voyageur ACV Open Water Performance

The open water speed and range characteristics are shown for the Voyageur ACV in Fig. 3-15 for a spread of average wave height conditions between zero and five feet. This range of wave heights includes the lower end of sea state 5.

FIG. 3-14

VARIATION OF ICEBREAKING SPEED AND FUEL CONSUMPTION PER MILE FOR THE VOYAGEUR ACV AND THE WTGB CLASS USCG CUTTER

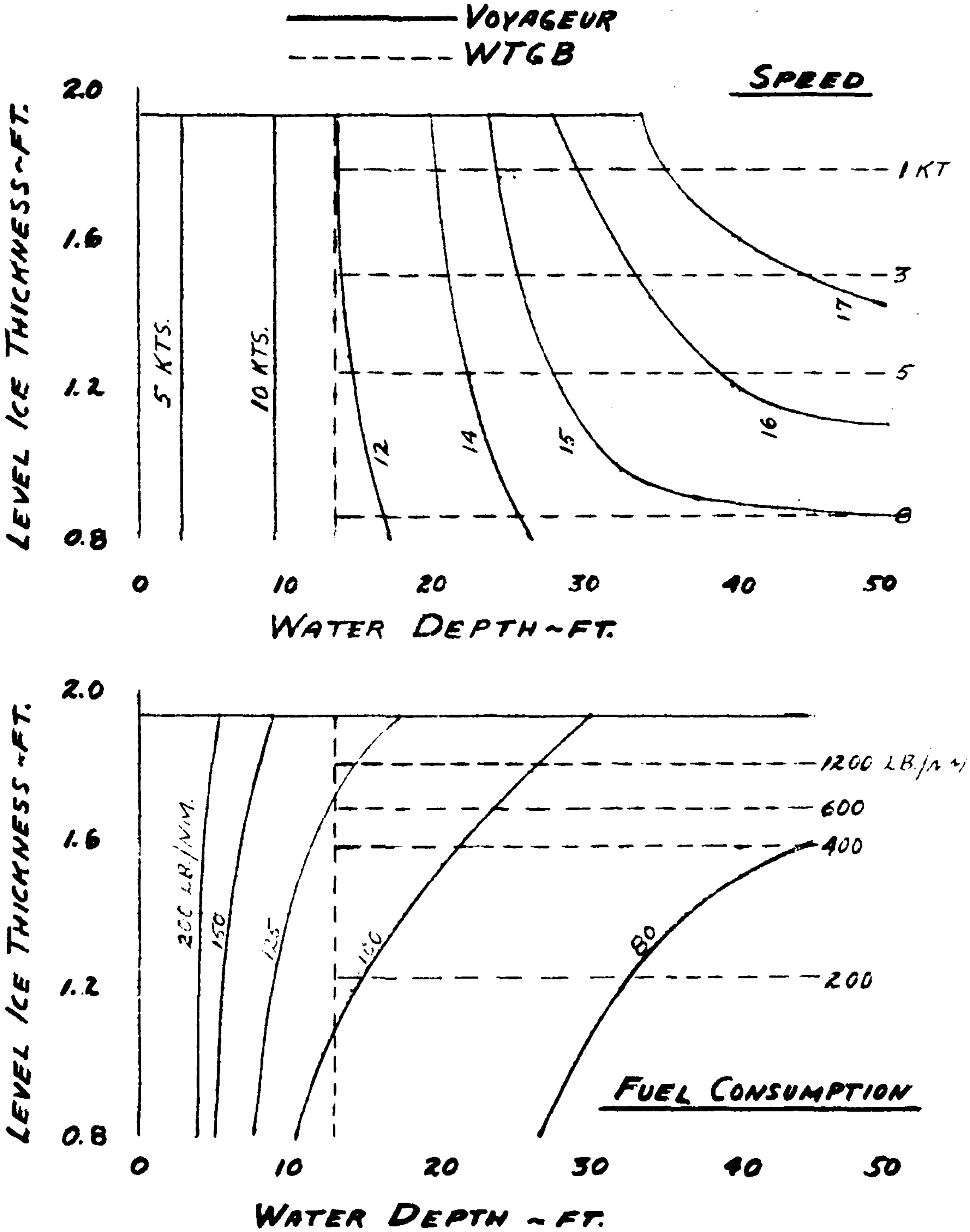
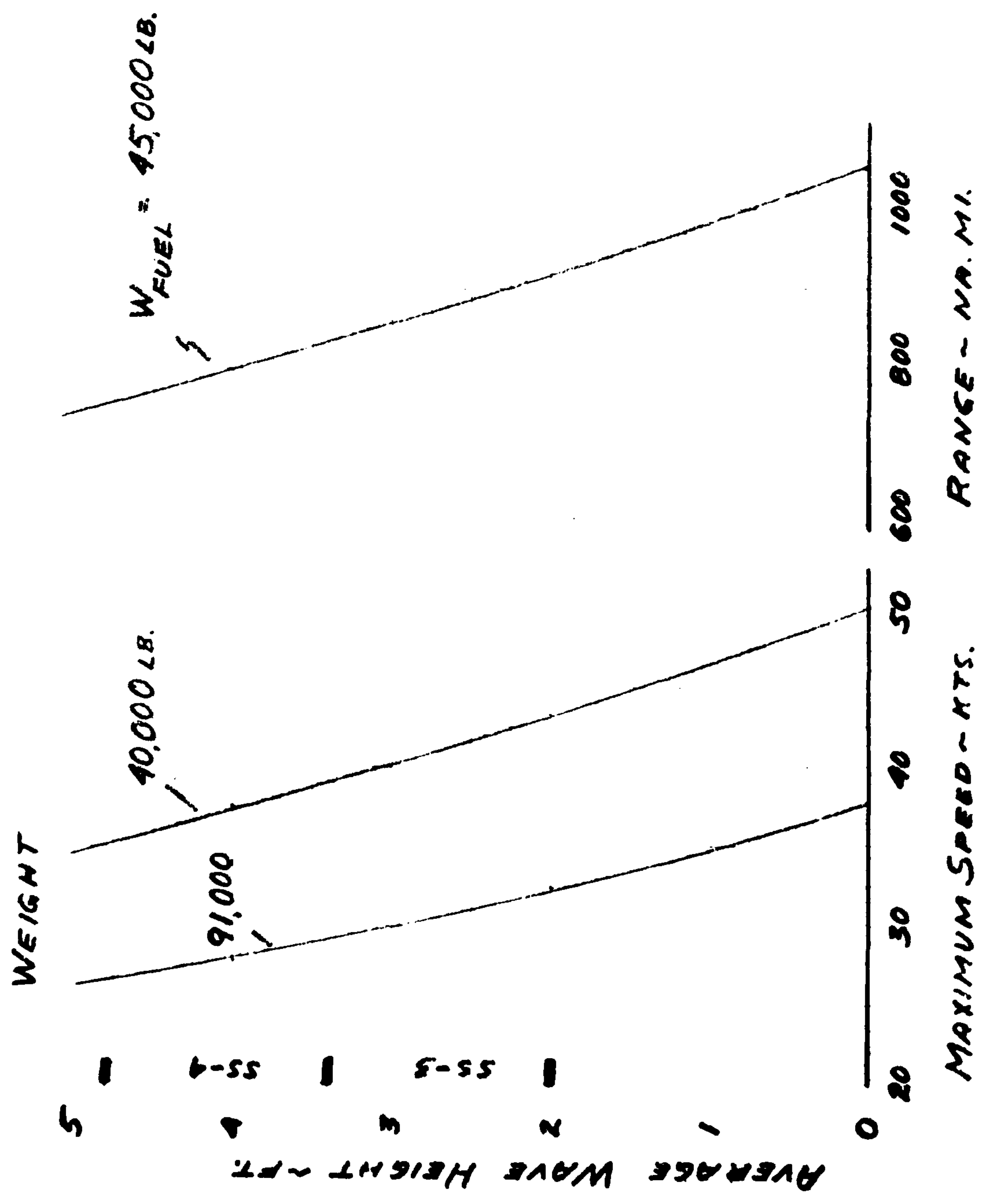


FIG. 3-15

EFFECT OF SEA CONDITIONS ON THE OPEN WATER PERFORMANCE OF THE VOYAGEUR AIR CUSHION VEHICLE

NORMAL RATED POWER = 1300 HP/ENG.



The descriptive definition of sea state 5 is "very rough". At its usual operating weights, the Voyageur calm water speed is in the 40 - 45 knot area. When the average wave height is 5 feet, the maximum speed with a rating of 1 300 HP for each of the ST6T-75 powerplants lies in the 30 knot range. For short periods of time, 1 800 HP per engine is available, and increases in speed of approximately 5 knots are achievable at the maximum power ratings.

The variation of the Voyageur ACV open water range with sea state is also shown in Fig. 3-15 for a fuel load of 45 000 pounds. A calm water range of 1 050 na. mi. is available. This is reduced to 740 na. mi. in seas with an average wave height of 5 feet. The Voyageur range exceeds the requirement over this spread of wave height conditions.

Voyageur ACV Sea State Capability

The consideration of the handling qualities of vessels in rough seas is a complex subject and a full examination of these factors is beyond the scope of this study. However, an incisive review which highlights some of the important factors is in order. This examination will focus upon two areas:

(1) the heave response to wave inputs in head and following seas

(2) the roll response to beam seas.

In the study of the heave response, it is well to examine the primary differences in the vehicle heave dynamics between the ACV and displacement hull cutters. In the case of the Voyageur ACV, the vehicle natural frequency in the heave mode is 3.6 hz, while that for the WTGB and WYTM is in the range of 0.2 hz. The cushion fan airflow provides substantial damping to the short period heave motion of an ACV. In the case of the Voyageur, the damping is

0.76 of the critical value (ζ = 0.76). With displacement ships, a much lesser portion of critical damping is present, leading to larger responses to the sea in the resonant frequency range. Because of these fundamental differences in the vehicle dynamics, the ACV and conventional cutters will respond quite differently to long and short waves.

In the cases in which the wave length is less than two times the cushion or hull length, both vehicles will tend to exhibit a "platforming" type of motion over the wave system. The vehicles do not follow the wave contours, but the vehicle motion responds to the vertical forces caused by the wave system. In the case of the ACV, the cushion pressure is altered by short waves of the critical lengths which cause the phenomenon known as wave pumping. With the displacement vessels, similar short waves of the critical lengths produce changes in the buoyancy force.

At wave lengths in excess of two times the cushion or hull length, both vehicles will tend to follow the contours of the wave system. This forcing frequency range is much below that of the "platforming" regime, and is well below the natural frequency of the Voyageur ACV. However, the forcing frequency due to long waves may be within the natural heave frequency of the WTGB and the WYTM. "Long waves" for the Voyageur ACV are associated with wave heights in excess of approximately 7 feet. "Long waves" for the WTGB are those whose height is above approximately 14 feet, while the corresponding wave height for the WYTM is in the 11 foot range. The high, long waves which are within the maximum wave height requirement of 20 feet can cause a resonant response with the two displacement hull cutters under certain operating conditions. This type of strong response to the wave system will not occur with the Voyageur ACV.

On the other hand, the response of the Voyageur ACV to "short waves" of less than 5 feet in height is likely to be larger and provide a rougher ride than is the case with the WTGB and the WYTM.

Table 3-1 presents a summary of wave height and sea state definitive descriptions.

Table 3 - 1

Sea State Descriptions

Sea State	Description	$h_{w_{avg.}}$	$h_{w_{sig.}}$	$h_{w_{1/10}}$
3	Moderate	2.0' to 3.4'	3.2' to 5.5'	4.2' to 6.8'
4	Rough	3.4' to 4.8'	5.5' to 7.7'	6.8' to 9.5'
5	Very Rough	4.8' to 8.1'	7.7' to 13.0'	9.5' 16.5'
6	High	8.1' to 14.0'	13.0' to 22.5'	16.5' to 28.0'

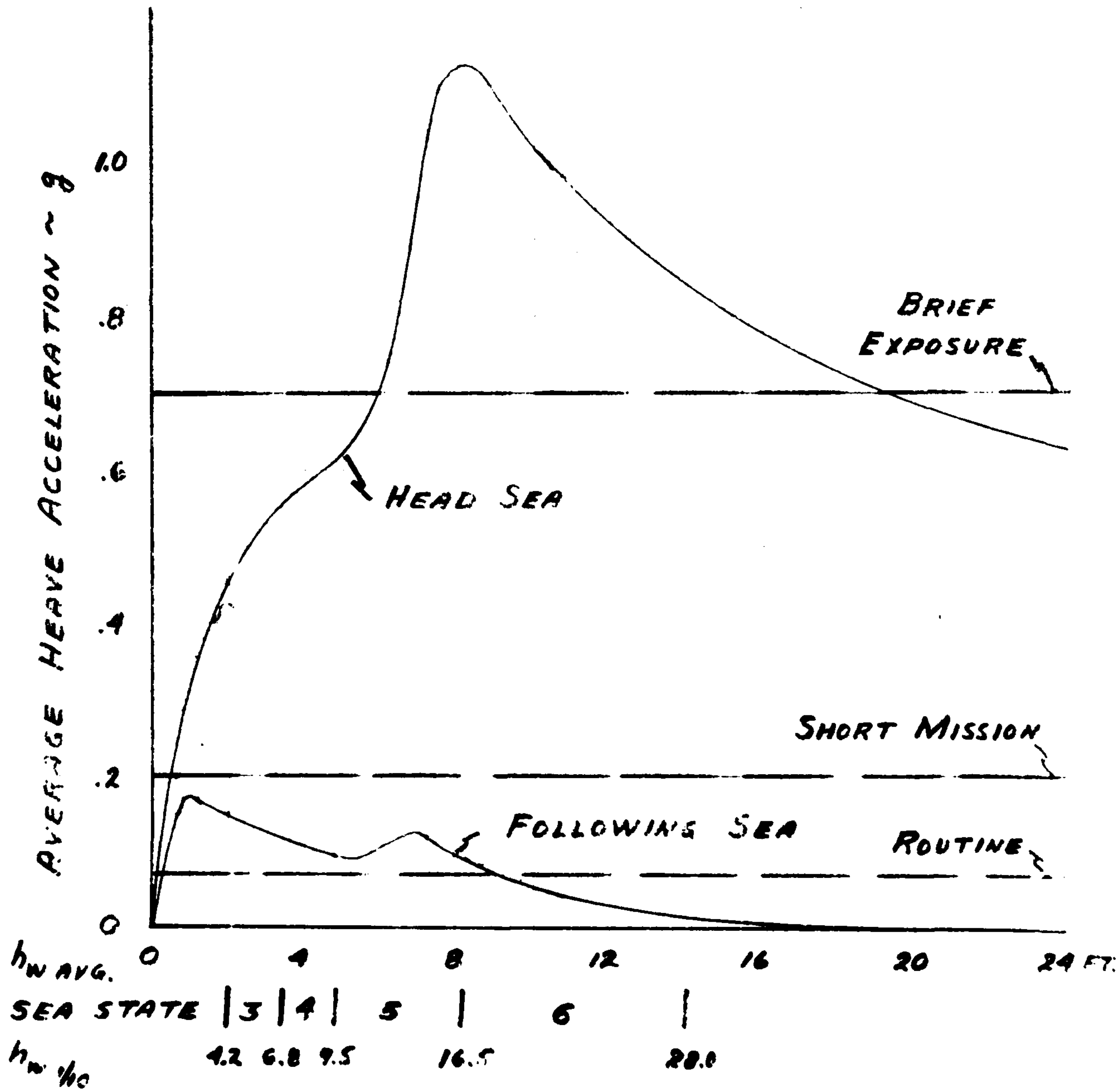
Fig.3-16 shows the predicted response of the Voyageur in heave as a function of average wave height at a speed of 30 knots. Operations into a head sea and with a following sea are depicted in the figure. The very great benefits of moving with the sea are apparent. Also shown are approximate human tolerance limits to vibratory motion for several operational mission durations. For these limits, the following definitions apply:

Routine Operations - 2 weeks or longer duration
Short Missions - 1 to 2 days in length
Brief Exposure - ½ to 1 hour duration

At the 30 knot speed, operations into head seas begin to approach the brief exposure limits in the environment of sea state 4. In sea states 5 and 6, it would appear to be well beyond the Voyageur capability to operate at 30 knots into head seas. On the other hand, operations at 30 knot speeds with following seas appear to be achievable thru sea state 6. The reductions in wave encounter frequency which result from the following seas produce

FIG. 3-16

PREDICTED EFFECT OF SEA CONDITIONS ON THE HEAVE ACCELERATION OF THE VOYAGEUR AIR CUSHION VEHICLE AT A SPEED OF 30 KTS.



major reductions in the ACV response.

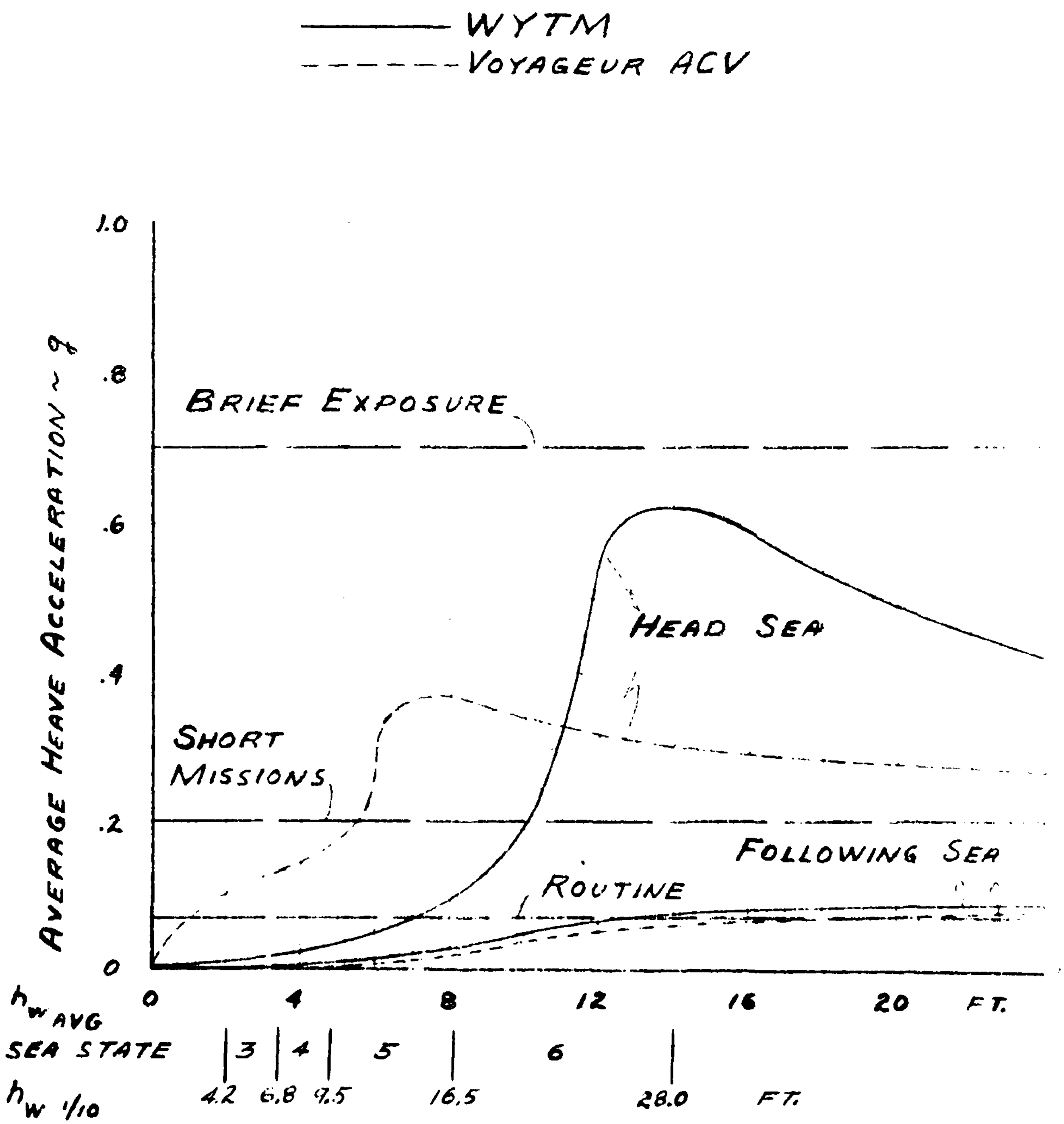
It is worthwhile to compare the heave response of the Voyageur and the WYTM and WTGB class cutters at the same vehicle speed into head and following seas. This has been done at a speed of 9 knots in Figs. 3-17 and 3-18.

The peak heave response of the Voyageur at the 9 knot speed occurs in head seas when the wave height is near 7 feet. A maximum value of heave acceleration of 0.37 g is developed. The wave encounter frequency for this maximum response condition is approximately 0.25 hz, and the peak in the heave response occurs in the wave contouring regime. At the 9 knot speed, the wave heights which are present at the Voyageur resonant frequency of 3.6 hz are less than 0.5 feet in height, and do not produce a large vehicle response in heave. For sea conditions below sea state 3, the Voyageur heave response meets the routine operations habitability criterion in head seas. The short mission habitability criterion is reached in head seas within the lower portion of sea state 5. In following seas, the Voyageur heave response is acceptable for routine operations over the full range of wave heights which have been considered.

The heave response of the WYTM class differs but little from the Voyageur ACV in following seas. In head seas, however, the heave response of the WYTM differs considerably from that of the Voyageur. It is superior to that of the ACV for wave heights of 11 feet or less. With higher waves, the WYTM heave response is substantially above that of the Voyageur, with a predicted peak acceleration increment of 0.63 g at wave heights of 14 feet. The wave encounter frequency for this condition is 0.2 hz, and is at the heave resonant frequency of the WYTM. This peak heave response also occurs in the wave contouring regime. It is worthy of note that when the average of the 1/10 highest waves is 14 feet, sea state 5 conditions prevail. Consequently, the peak heave response of 0.63 g is present to a noticeable extent in sea state 5 operations of the WYTM.

FIG. 3-17

COMPARISON OF THE PREDICTED EFFECT OF SEA CONDITIONS ON THE HEAVE ACCELERATION OF THE WYTM AND THE VOYAGEUR ACV AT 9 KTS.



The main deck height of the WYTM above the waterline is 3.5 feet. For values of the heave acceleration increment which are in excess of approximately 0.35 g, water will be taken over the main deck of the cutter. Consequently, it would appear that wave heights in excess of 11 feet result in seakeeping difficulties which tend to preclude operations into head seas. Since the average of the 1/10 highest waves is 11 feet in the lower reaches of sea state 5, this sea condition may be expected to represent the operating limit of the WYTM into head seas.

The heave response of the WYTM into head seas meets the routine mission habitability criterion into the sea state 5 region. In following seas, the average heave acceleration criterion for routine operations is met thru sea state 6. The primary heave response weaknesses of the WYTM class cutter stem from the low freeboard of the cutter and its large response to long, high waves which are present, but in reduced distribution intensities, at lower sea state conditions into sea state 4.

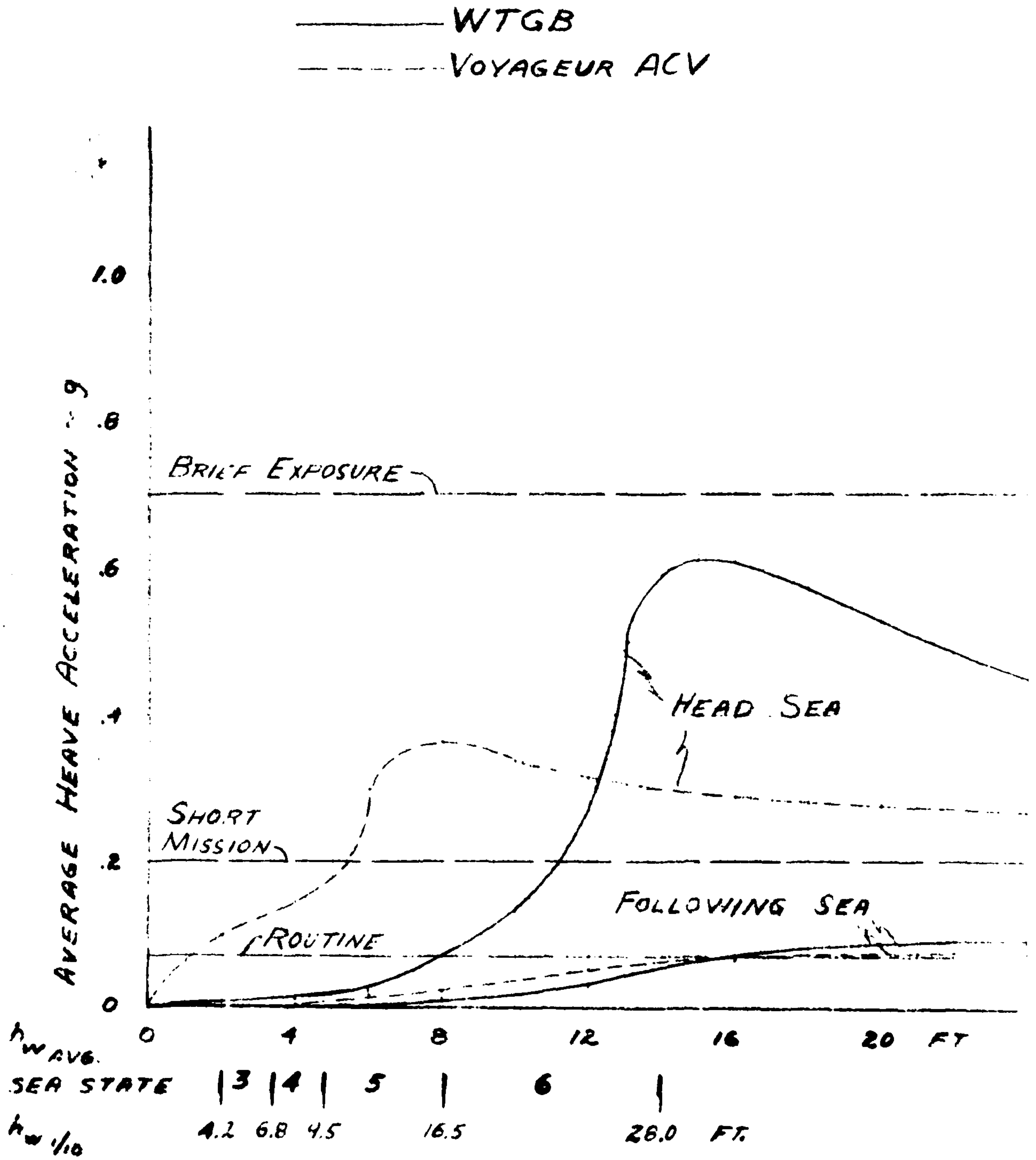
The comparison of the heave response of the Voyageur ACV and the WTGB class cutter is shown in Fig. 3-18. The WTGB benefits from its being a larger vessel than the WYTM. Its heave response is generally similar to that of the WYTM, but its peak heave response of 0.61 g occurs at wave heights in the 16 foot area. Consequently, the WTGB class possesses somewhat better seakeeping characteristics in operations thru sea state 6, and provides an extended operating capability beyond that of the WYTM.

The minimum freeboard of the WTGB is 6.0 feet, and is predicted to be sufficient to prevent water to be taken over the main deck of the cutter in rough water operations into head seas. Consequently, this factor is not expected to limit the WTGB operations at the 9 knot speed which has been investigated in the limited analysis of this study.

However, the heave response of the Voyageur ACV into head seas is

FIG. 3 - 18

COMPARISON OF THE PREDICTED EFFECT OF SEA CONDITIONS ON THE HEAVE ACCELERATION OF THE WTGB AND THE VOYAGEUR ACV AT 9 KTS.



significantly reduced from that of the WTGB for wave heights above 12 feet, and the ACV is predicted to possess appreciably better seakeeping characteristics into head seas with long, high waves. In general, the WTGB class will behave better than the Voyageur ACV in sea conditions below sea state 5, but will provide poorer seakeeping characteristics in the higher sea states.

An air cushion vehicle does not have a problem with taking green water over the deck because of the rapid buildup of the cushion pressure with reduced cushion depth which results if the sea deflects the skirt upward toward the wet deck of the craft. It is necessary, however, to design the fan system so that the fan is capable of providing pressure levels which are in excess of those which are developed in the cushion during operations in rough water. It is the usual practice of the ACV operator to increase the fan RPM during operations in the higher seas, in order to provide for increased fan discharge pressure and fan air flow.

The roll response of the three vehicles will be examined in beam seas. As in the study of the heave response, the geometry of the wave system is an important factor in the seakeeping characteristics in the roll mode. A wave length to height ratio of 20 will be employed in the roll characteristics study, as was used in the foregoing heave analysis. This wave geometry is closely similar to that of the Pierson- Moskowitz sea spectrum which is widely utilized and is considered to provide a good representation of sea conditions. The maximum slope of individual waves is 9.0 degrees for the wave length to height ratio of 20. It is recognized that steeper waves do exist, and that such a wave environment would lead to larger roll angles for each of the three systems being considered.

In the case of the Voyageur ACV, its length to beam ratio of 1.7 is low by the standards of displacement ships, and its relatively broad beam acts to

constrain the roll angles of the vehicle. The rolling motion of the ACV is also restrained by the contact of the skirt bag with the water surface in the cases in which the skirt fingers may be temporarily knuckled under by the sea. The incremental roll angle which results from this type of deflection of the skirt fingers is limited to 3.6 degrees, with a finger depth of 2 feet. Consequently, the Voyageur ACV roll angle in rough seas appears to be limited to the range of 13 degrees. However, if steeper waves are encountered, the rolling motion excursions would also increase with the ACV as would also be the case with the displacement hull cutters.

The natural roll period of the WYTM class cutter is 8.1 seconds, which yields a natural frequency in roll of 0.78 rad./sec. The forcing frequency leading to roll resonance in beam seas is realized with a beam sea of 15.9 feet wave height. Roll angles which are several times the wave slope are to be expected at the resonant conditions with conventional hull configurations. Consequently it would appear that the Voyageur ACV would experience roll characteristics in rough water which are superior to those of the WYTM. This would appear to be particularly true in the case of the steeper wave environment.

A similar quantitative comparison between the Voyageur ACV and the WTGB class of cutters with respect to the roll response in rough water is to be expected. Since the beam of the WTGB is larger than that of the WYTM, 37.5 feet to 27.2 feet, it is proportionally stiffer in roll, compared with the WYTM.

IV SUMMARY OF UNITED STATES COAST GUARD PROGRAMS AND MISSIONS

The overall objective of this study effort is a definitive evaluation of the air cushion vehicle concept with respect to its employment by the U.S. Coast Guard in the fulfillment of its program activities. A prerequisite to the implementation of the study is the definition of the tasks and missions which must be accomplished to meet the program requirements.

The study of the program requirements which are imposed upon the U.S. Coast Guard has included discussions with the USCG Headquarters staff, 1st and 9th District staff personnel, and Sault Ste. Marie and Portland Group personnel. The program identification and groupings which have emerged from this work is shown in Table 4-1. The six Coast Guard mission areas which are included in this comparative study are:

- Ice Management
- Search and Rescue
- Aids to Navigation
- Marine Environmental Protection
- Safety, Security and Law Enforcement
- Logistics and Administration

The Abstracts of Operations for several Coast Guard cutters including the Katmai Bay, Acacia, Yankton and Snohomish were studied to assess whether this grouping properly categorized the operations which were conducted by these vessels, and whether it was sufficiently broad to include all reported underway time properly. Additionally, the mission breakdown was examined for compatibility with the 10 Year Cutter Plan, Ref. 10.

The first five program areas represent the activities thru which the Coast Guard meets its external requirements. The sixth area of activity, Logistics and Administration, includes the activities which are largely internal to the Coast Guard.

Within each of the program areas, a limited number of missions were identified to provide a focus upon the next level of detail within the program area. Each of the six program areas will now be reviewed with respect to the associated missions within the program.

Ice Management

The ice management program was divided into two mission areas, icebreaking and flood control. The two functions, while closely related, involve considerably different objectives and required operating techniques.

The icebreaking mission was further sub-divided into port and waterway operations. The icebreaking in ports involves the opening of an area in which ships may conduct embarkation, docking, and the related maneuvering operations. Along the waterways, a channel thru which ships may navigate must be opened, and of a width to permit ship passing movements as may be necessary.

The flood control aspect of ice management is associated with the prevention and breakup of ice jams which obstruct the downstream flow of water during the winter thaws and spring runoff. This may involve preventive icebreaking actions at a time in the season prior to the actual emergence of a flooding problem. Flood control activities are primarily associated with operations in rivers and streams, although some operations in smaller lakes have been previously required.

Search and Rescue

The search and rescue program was also separated into two missions which,

in this case, are closely related. The first mission relates to the conduct of the search and the establishment of contact with the distressed party by the rescue vehicle. This task is associated with the problem of getting the men and equipment to the problem site. The speed and response time of the Coast Guard unit which is assigned are important factors.

The second of the search and rescue tasks is the actual providing of assistance. The required types of assistance were categorized into the towing, medical and mechanical forms of activity. In the large majority of cases a mechanical problem leads to the requirement for a tow.

Aids To Navigation

The natural mission breakdown within the aids to navigation program evolves into two mission areas, the first of which is the deployment and positioning of the aids. The second mission is associated with the servicing of the aids and light stations. Included in the servicing task is the re-positioning of any aids which have been moved out of position by storm action or other events.

Marine Environmental Protection

This program area has not resulted in a substantial requirement for cutter operating hours in the 1st and 9th Districts for the cutters Katmai Bay, Acacia, Yankton and Snohomish. However, the program area is one of high visibility and potential importance since incidents, when they occur, may have substantial economic impact and be accorded extensive media attention.

The program area has been broken into two missions, the deployment and utilization of the environmental protection equipment, together with the

area inspection and patrol necessary to the identification and assessment of marine environmental problems. Oil spills have been highlighted as the major problem area and the equipment deployment task is associated with the positioning of booms for spill containment and the use of absorptive material for the removal of the oil from the water.

Safety, Security and Law Enforcement

This program area is concerned with the types of policing activities which are assigned to the Coast Guard within its overall role. A primary function within the program area is the enforcement of domestic laws and international treaties which are related to the fishing industry. The interdiction and apprehension of vessels which deal in various types of contraband goods such as drugs also falls into this program area. The waterborne activities which are related to port security represent an additional mission responsibility of the Coast Guard.

The missions which have been identified within this program area are two in number. The first of which is that of area inspection and patrol to provide the surveillance which is necessary to uncover problems in safety or illegal activities. The second mission is the interdiction and apprehension of violators when the patrol activity or other source identifies a violation of law or treaty.

A primary advantage of this task breakdown of the safety, security and law enforcement program stems from the fact that it provides an opportunity to assess the cutter performance differences between the patrol and chase aspects of the program responsibilities.

Logistics and Administrative

The inclusion of this program area was suggested by Capt. Joseph Wubbold, Commander of the Sault Ste. Marie USCG Group. It is related to the operating requirements which are imposed upon the cutters in the fulfillment of internal Coast Guard and national security needs. The first of the three mission areas is that of training, including the military training activities. The second mission area includes operations which are related to public affairs and recruiting. The third mission area includes the operations which are conducted to meet the internal logistics needs of the Coast Guard.

The needs of this program area are met with resources which are already available within the Coast Guard fleet, and, as such, normally do not impose special performance requirements upon the USCG vessels. The operations which are conducted within this program area are of sufficient extent and significance to warrant classification for the purposes of this study.

Table 4-1

United States Coast Guard Program and Mission Classification

I Ice Management

- A. Icebreaking
  1. Ports
  2. Waterways
- B. Flood Control
  1. Rivers and streams
  2. Lakes

II Search and Rescue

- A. Search and contact
- B. Assistance
  1. Towing
  2. Medical
  3. Mechanical

III Aids to Navigation

A. Equipment deployment

B. Equipment servicing

IV Environmental Protection

A. Equipment deployment

B. Area inspection and patrol

V Safety, Security and Law Enforcement

A. Area inspection and patrol

B. Interdiction and apprehension

VI Logistics and Administration

A. Training

B. Public affairs and recruiting

C. Logistics

V EFFECTIVENESS AND UTILIZATION ANALYSIS

Certain Coast Guard programs which are of significance within the role of the USCG have been summarized in Chapter IV and were categorized into six basic program areas. The comparative assessment of the WTGB class cutter and the comparable ACV in the accomplishment of the selected programs and associated missions is addressed in this chapter.

This comparative assessment is undertaken in the following steps:

(1) the definition of the desired performance level which is needed for the full capability of mission accomplishment for each item of a group of relevant vehicle performance parameters.

(2) the quantitative evaluation of the characteristics of the WTGB and the Voyageur ACV, with respect to the defined requirement. The Voyageur was chosen since its level icebreaking capability is closely similar to the WTGB. Each vehicle is evaluated in accordance with the following scale:

Full Capability	4 points
Good Capability	3
Adequate Capability	2
Some Capability	1
No Capability	0

(3) the expected utilization of the WTGB and ACV, expressed in terms of operating hours per month for each mission will be assessed. Past experience and the capability evaluation will provide the data base from which this assessment is made.

Selection of Vehicle Performance Characteristics

The vehicle performance parameters which are relevant to the accomp-

lishment of the Coast Guard programs must be carefully selected so that the full scope of the required vehicle capabilities is identified. The chosen performance parameters must include each of the important vehicle capabilities which are related to the complete listing of programs and missions. A given performance parameter may very well have differing levels of performance required for the various programs and the missions within a given program area. For example, the endurance requirement for the ice management program may well be different from that for the safety, security and law enforcement program.

A total of twelve vehicle performance parameters have been identified and are listed in Table 5-1.

Table 5-1

Vehicle Performance Parameters for Coast Guard Missions

Level Ice Thickness
Broken Ice Channel Width
Speed of Advance Thru the Ice Field
Response Time to Initiate the Mission or Task
Vehicle Speed Capability
Vehicle Sea State Capability
Vehicle Operating Range
Vehicle Operating Endurance
Maximum Useful Draft
Towing Bitt Pull
Payload Weight
Payload Handling/Operating Capability

An examination of Table 5-1 indicates that three of the vehicle performance parameters are related to the speed capability of the Coast Guard craft. However, these three speed related parameters are intended to measure

rather different performance requirements and capabilities with respect to the Coast Guard missions. For example:

- The speed of advance thru an ice field is a function of the vehicle speed as it makes an icebreaking pass, and also must reflect the need, if any, for repetitive passes over a given stretch of ice for the purposes of channel widening and/or improved ice clearing. The ice field thickness clearly influences the speed of advance thru the ice field.
- The response time to initiate a mission must include the start-up time from a cold plant condition prior to getting underway, as well as the transit time to the mission site.
- The vehicle speed capability is a measure of its open water speed. As a case in point, it is related to the mission capability for the interdiction of a suspect vessel which has been identified during a law enforcement patrol mission operation.

In other instances, the vehicle performance parameters may present an incomplete measure of the total mission requirement with respect to an operation. The towing bitt pull parameter is far from the only consideration with respect to the suitability of a Coast Guard vehicle for towing, although the towing bitt pull parameter is fundamental and important. It is recognized that the ease and safety of attaching the towline, the ability to monitor the towed vessel from the bridge of the Coast Guard craft, as well as other factors are of substantial importance in the considerations of the overall suitability of a vehicle for the towing function.

The first three of the listed requirements are related to the ice management program. The design icebreaking capability of an icebreaker is usually related to the thickness of level ice which it is capable of breaking. The channel width requirement for icebreaking is related to the beam of the vessel being assisted thru the ice field. The widening of a broken ice channel, as well as improvements in the quality of the channel ice clearing, will

act to reduce the resistance of a ship in its transit of an ice filled route segment. The necessary provisions for the passing of marine traffic are also related to the width of the broken and cleared ice channel.

The speed of advance thru an ice field is considered to be the rate at which the icebreaking vehicle can open a channel of the necessary width to support shipping operations. It may not be equal to the icebreaker speed thru the ice field, as in the case in which two icebreaking passes are required to open a channel of sufficient width for shipping.

The response time must include the period needed to get underway in meeting a call, in addition to the transit time from homeport to the site objective of the particular sortie.

The sea state capability of a vessel determines the weather conditions which limit the ability of the vessel to respond to meet a demand for service. Such factors as roll stability, heave dynamics and the taking of green water, slamming loads, en route ice accumulation or the conduct of the on site task operations may reflect limiting sea state capabilities. The technical terms seakeeping, sea kindliness and seaworthiness all relate to sea state capability considerations.

The range requirement must reflect the transit distance to the mission site, in addition to the on site task activity. For example, if a 10 hour patrol at 12 knots is required to be performed at an area which is 150 na. mi. from the home port, the total range requirement for the mission would be 420 na. mi.

The operating endurance requirement is established by the underway time which is associated with the accomplishment of an assigned mission. The fuel load and habitability characterisics of the vessel must be compatible with

the defined endurance requirements.

The maximum usable draft parameter is determined as the deepest vessel draft which will still permit full mission capability. As an example, if a flood control operation must be conducted in an area in which the water depth is three feet, the deepest vehicle draft allowable for this operation must be less than three feet. Consequently, the maximum usable draft in this case is three feet.

A requirement for a cutter to tow other vessels, buoys or equipment arises in the search and rescue, aids to navigation, environmental protection, and safety, security and law enforcement programs. It includes such activities as the towing of disabled vessels; the repositioning of navigation aids; the deployment of environmental protection equipment (booms). The required towing bitt pull force varies with the program needs, and lies in the range between 1 and 10 tons.

The payload requirements which are defined in terms of weight, space for operations, the necessary handling equipment, storage volume, visibility requirements from the bridge, etc. are obviously mission dependent considerations which may vary widely among the Coast Guard programs. In general, however, the payload and associated equipment will require the vehicle platform to provide an identifiable weight carrying capacity, and the operating area, foundations and storage volume to permit the missions to be implemented. The visibility from the bridge and an absence of blind spots to the stern are important factors in many operations, particularly those which involve the towing of another vessel or navigation aid.

The twelve performance requirement parameters which have been considered in the discussion above appear to identify the vehicle characteristics which are relevant to Coast Guard Operations. The performance re-

quirements for the 1st District operations have been defined by the staff of the Portland Group and are reproduced in Table 5-2. Similar data for 9th District operations were identified by the Sault Ste. Marie Group staff and are presented in Table 5-3.

Cutter Evaluations Against the Performance Requirements

The 110 foot WYTM and the 140 foot WTGB classes of Coast Guard cutters have been evaluated against the vehicle performance requirements of Tables 5-2 and 5-3 respectively. The WYTM evaluation of Table 5-4 represents the Portland Group assessment of the cutter capability, while the WTGB evaluation of Table 5-5 reflects the inputs of the Sault Ste. Marie Group.

The cutter performance data of Tables 5-4 and 5-5 have been further analyzed to obtain a clearer picture of the strengths and weaknesses of the WYTM and WTGB relative to the perceived performance requirements. The general technique of averaging and weighing the individual scores was employed. For each cutter, an average evaluation score was obtained for each performance characteristic for each of the program areas, not including the Logistics and Administration activity. These data are shown in Tables 5-6 and 5-7 for the 110 foot WYTM in 1st District operations and the 140 foot WTGB in 9th District operations.

It is apparent that the performance evaluation of the cutters must be weighted to reflect their actual utilization in program operations. The summary data of Table 5-8 reflects the actual employment of the WYTM class cutters Yankton and Snohomish over a three year period ending 30 June 1979 in 1st District operations.

Table 5 - 2

PERFORMANCE REQUIREMENTS FOR THE COAST GUARD TASKS AND MISSIONS

OPERATING TASK	VEHICLE PERFORMANCE REQUIREMENT					First District Deployment (Group Portland)						
	Ice Thickness	Ice Channel Width	Speed of Advance	Response Time	Vehicle Speed	Sea State Capability	Range	Endurance	Draft	Towing Bitt Pull	Payload Weight	Necessary Equipment
I Ice Management						Enroute 10' avg.						Harner Winch Dewatering (2 tons)
A. Icebreaking												
1. Ports	2½' max.	¼-½ mi.	3-5 kts.	1-4 days	10-15 kts.	20' max.	500 na.mi	3-5 days	5' minor	N/A	N/A	
2. Waterways	2½' max.	200'	3-5 kts.	1-4 days	10-15 kts.		500 na.mi	3-5 days	15' major	N/A	N/A	
B. Flood Control												
1. Rivers and Streams	2½' max.	Bank to bank	3-5 kts.	7 days	10-15 kts.	30 kt. wind	200 na.mi	1 day	10'	N/A	N/A	As above
2. Lakes	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	—
II Search and Rescue												
A. Establishing Contact	Same as Item I	Dependent upon beam of vessel to be assisted	8-10 kts.	4 hrs.	35-40 kts	20' max.	150 na.mi	3 days	3'	-	3 tons	Tow & SAR Equipment (3 tons)
B. Providing Assistance												
1. Towing			1-3 kts.	12 hrs.	8-12 kts.	14-16' max.	300 na.mi Round trip	3 days	3'	10 tons	3 tons	360° visibility from bridge
2. Medical			-	A/C used	-	-	-	-	-	-	-	-
3. Mechanical			1-3 kts.	12 hrs.	12 kts.	4'(boarding)	300 na.mi Round trip	3 days	3'	10 tons	3 tons	1 EMT
III Aids to Navigation	Same as Item I	Same as Item I	Same as Item I		Not Critical					10 tons full capability; 3 tons useful	10-15 tons total	6 000 lbs lift capacity
A. Equipment Deployment				24 hrs.		15-20'	150 na.mi Round trip	1 day	0' would be useful			
B. Equipment Servicing				24 hrs.		6-8'		1 day			As above	
IV Environmental Protection	Same as Item I for Transit	Same as Item I for Transit	Same as Item I for Transit									Booms and Deployment Gear Absorbers
A. Equipment Deployment				2-4 hrs.	10-12 kts.	20' max.	100 na.mi Round Trip	3-5 days	0' would be useful	2 000 lbs.	3 tons	
B. Area Surveillance				½-2 hrs.	25 kts.	6'-8'	As above	3-5 days		2 000 lbs.	3 tons	
V Safety and Law Enforcement	N/A	N/A	N/A							10 tons full capability; 3 tons useful		Boarding and Towing Gear Armament
A. Inspection and Patrol				Planned Operation	15 kts.	4'	500 na.mi Round trip	3-5 days	3'		3 tons	
B. Interdiction & Apprehension				Immediate	35 kts.	8' max. for pursuit 4-6' boarding	300 na.mi Round trip	1-2 days	3'		3 tons	

TABLE 5-3

PERFORMANCE REQUIREMENTS FOR THE COAST GUARD TASKS AND MISSIONS

OPERATING TASK	VEHICLE PERFORMANCE REQUIREMENT FOR THE Ninth District Deployment (Group Sault Ste. Marie)											
	Ice Thickness	Ice Channel Width	Speed of Advance	Response Time	Vehicle Speed	Sea State Capability	Range	Endurance	Draft	Towing Bitt Pull	Payload Weight	Necessary Equipment
I Ice Management												
A. Icebreaking												
1. Ports	4' level	150'	Not Critical	1 day	Not Critical	30 - 40 kt Wind Speed	1000 na. mi. in open water	5 days	Less than 10 ft.	Limited by strength of 5½" nylon in ice.	Minimal	Minimal
2. Waterways	Refrozen brash to bottom	150'		3-4 hours				5 days	Less than 15 ft.			
B. Flood Control												
1. Rivers and Streams	1-2 ft.	Bank to bank		1 day		30-40 kt. Wind Speed	As above	5 days	Less than 6'	2 tons	Minimal	Minimal
2. Lakes	-	-	-	-	-	-	-	-	-	-	-	-
II Search and Rescue												
A. Establishing Contact	4' level + ridges	N/A	40 kts.	6 hrs. Winter 1-3 hrs. Summer	40 kts.	SS-4	600 na.mi. - Winter	2 days	4 ft.	-	Minimal	Minimal
B. Providing Assistance												
1. Towing	Same as Item IA1 and Item IA2	75'	1-3 kts.	As above	8-12 kts.	SS-4	200 na.mi. - Summer	2 days	4 ft.	18 tons	Minimal	Minimal
2. Medical		A/C Used	-	-	-	-	-	-	-	-	-	-
3. Mechanical		-	N/A	As above	N/A	SS-4		2 days	4 ft.	-	Minimal	Minimal
III Aids to Navigation												
A. Equipment Deployment	4' level	N/A	Not Critical	48 hrs.	Not Critical	Not Critical	50 na.mi.	2 days	4 ft.	18 tons	10 000 lb.	4000 lb.hoi
B. Equipment Servicing	4' level	N/A		48 hrs.		SS-2	50 na.mi.	2 days	4 ft.	18 tons	10 000 lb.	4000 lb.hoi
IV Environmental Protection												
A. Equipment Deployment	Not Critical	Not Critical	Not Critical	2-3 hrs.	Not Critical	SS-1-2 for boom effectiveness	50 na.mi.	2 days	4 ft.	1 000 lb.	Minimal	Minimal
B. Area Surveillance				2-3 hrs.			50 na.mi.	2 days	4 ft.	1 000 lb.	Minimal	Minimal
V Safety and Law Enforcement												
A. Inspection and Patrol	4' level + brash	N/A	40 kts.	Not Critical	40 kts.	SS-3	1 000 nm.	2-4 days	4 ft.	N/A	N/A	N/A
B. Interdiction & Apprehension		N/A	40 kts.			SS-3	1 000 m.	2-4 days	4 ft.	N/A	N/A	N/A

Grading System - Full Capability - 4
Good Capability - 3
Adequate Capability - 2
Some Capability - 1
No Capability - 0

VEHICLE EVALUATION AGAINST THE PERFORMANCE REQUIREMENTS FOR THE COAST GUARD TASKS AND MISSIONS

TABLE 5-1

OPERATING TASK	VEHICLE EVALUATION GRADE SCORE FOR THE WIG - First District Deployment (Group Portland)											
	Ice Thickness	Ice Channel Width	Speed of Advance	Response Time	Vehicle Speed	Sea State Capability	Range	Endurance	Draft	Towing Bitt Pull	Payload Weight	Necessary Equipment
I Ice Management												
A. Icebreaking												
1. Ports	3	3	2-3	4	2	2	4	4	0	N/A	N/A	4
2. Waterways	3	4	2-3	4	2	2	4	4	4	N/A	N/A	4
B. Flood Control												
1. Rivers and Streams	3	3	2-3	4	2	2	4	4	0	N/A	N/A	4
2. Lakes	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
II Search and Rescue												
A. Establishing Contact	3	4	4	1	0	2	4	4	0	-	4	4
B. Providing Assistance												
1. Towing	3	4	4	3	3	2	4	4	0	4	4	0
2. Medical	A/C Used	-	-	-	-	-	-	-	-	-	-	-
3. Mechanical	3	4	4	4	3	1	4	4	0	4	4	0
III Aids to Navigation												
A. Equipment Deployment	3	3	3	4	Not Critical	2	4	4	0	4	4	4
B. Equipment Servicing	3	3	3	4		3	4	4	0	4	4	4
IV Environmental Protection												
A. Equipment Deployment	3	3	3	2	3		4	4	0	4	4	4
B. Area Surveillance	3	3	3	1	0	3	4	4	0	4	4	4
V Safety and Law Enforcement												
A. Inspection and Patrol	N/A	N/A	N/A	4	0	4	4	4	0	4	4	4
B. Interdiction & Apprehension				1	0	2 1	4	4	0	4	4	4

VEHICLE EVALUATION AGAINST THE PERFORMANCE REQUIREMENTS FOR THE COAST GUARD TASKS AND MISSIONS

Grading System - Full Capability - 4
Good Capability - 3
Adequate Capability - 2
Some Capability - 1
No Capability - 0

TABLE 5-5

VEHICLE EVALUATION GRADE SCORE FOR THE WTGB - NINTH DISTRICT (Group Sault Ste. Marie)

OPERATING TASK	Ice Thickness	Ice Channel Width	Speed of Advance	Response Time	Vehicle Speed	Sea State Capability	Range	Endurance	Draft	Towing Bitt Pull	Payload Weight	Necessary Equipment
I Ice Management												
A. Icebreaking												
1. Ports	2	3	Not	4	3	4	4	4	1	4	4	4
2. Waterways	3	4	Critical	4	3	4	3	4	4	4	4	4
B. Flood Control												
1. Rivers and Streams	4	4	As above	4	3	4	4	4	0	4	4	4
2. Lakes	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
II Search and Rescue												
A. Establishing Contact	2	N/A	2	2	1	4	4	4	1	–	4	4
B. Providing Assistance												
1. Towing	3	4	3	4	4	4	4	4	1	4	4	4
2. Medical	–	–	–	–	–	4	4	4	0	–	4	4
3. Mechanical	3	–	N/A	4	4	4	4	4	1	–	4	4
III Aids to Navigation												
A. Equipment Deployment	2	N/A	Not	4	Not	Not Critical	4	4	1	4	4	4
B. Equipment Servicing	2	N/A	Critical	4	Critical	4	4	4	1	4	4	4
IV Environmental Protection												
A. Equipment Deployment	Not	Not	Not	2	Not	4	4	4	1	4	4	4
B. Area Surveillance	Critical	Critical	Critical	1	Critical	4	4	4	1	4	4	4
V Safety and Law Enforcement												
A. Inspection and Patrol	2	N/A	2	Not	2	4	4	4	1	N/A	N/A	N/A
B. Interdiction & Apprehension	2	N/A	2	Critical	0	4	4	4	1	N/A	N/A	N/A

TABLE 5-6

VEHICLE WYTM DISTRICT FIRST (GROUP PORTLAND)

PERFORMANCE PARAMETER / PROGRAM	AVERAGE EVALUATION SCORE											
	t_{ICE}	ICE CHANNEL WIDTH	SPEED OF ADVANCE	RESPONSE TIME	SPEED	SEA STATE	RANGE	ENDURANCE	DRAFT	TOWING BITT PULL	PAYLOAD	PAYLOAD HANDLING
ICE MANAGEMENT	3	3.3	2.5	4	2	2	4	4	1.3	N/A	N/A	4
SEARCH & RESCUE	3	4	4	2.7	2	1.7	4	4	0	4	4	1.3
AIDS TO NAVIGATION	3	3	3	4	NOT CRITICAL	2.5	4	4	0	4	4	4
ENVIRONMENTAL PROTECTION	3	3	3	1.5	1.5	2.5	4	4	0	4	4	4
SAFETY, SECURITY & LAW ENFORCEMENT	N/A	N/A	N/A	2.5	0	3.0	4	4	0	4	4	4
WEIGHTED AVERAGE	3.0	3.5	3.1	3.2	1.2	2.3	4	4	0.5	4	4	3.3

TABLE 5-7

VEHICLE WTGB DISTRICT NINTH (GROUP SAULT STE MARIE)

PERFORMANCE PARAMETER / PROGRAM	AVERAGE EVALUATION SCORE											
	t_{ICE}	ICE CHANNEL WIDTH	SPEED OF ADVANCE	RESPONSE TIME	SPEED	SEA STATE	RANGE	ENDURANCE	DRAFT	TOWING BITT PULL	PAYLOAD	PAYLOAD HANDLING
ICE MANAGEMENT	3.0	3.7	N/C	4.0	N/C	4.0	3.7	4.0	1.7	4.0	4.0	4.0
SEARCH & RESCUE	2.7	4.0	2.7	3.3	3.0	4.0	4.0	4.0	0.8	4.0	4.0	4.0
AIDS TO NAVIGATION	2.0	N/A	N/C	4.0	N/C	4.0	4.0	4.0	1.0	4.0	4.0	4.0
ENVIRONMENTAL PROTECTION	4.0	N/C	N/C	1.5	N/C	4.0	4.0	4.0	1.0	4.0	4.0	4.0
SAFETY, SECURITY & LAW ENFORCEMENT	2.0	N/A	2.0	N/C	1.0	4.0	4.0	4.0	1.0	N/A	N/A	N/A
WEIGHTED AVERAGE	2.66	3.77	2.23	3.75	1.67	4.0	3.85	4.0	1.32	4.0	4.0	4.0

Table 5-8

Program Utilization of the WYTM in the 1st District

Program	% Underway Time
Ice Management	36.6 %
Search and Rescue	21.4
Aids to Navigation	2.1
Environmental Protection	0.8
Safety, Security and Law Enforcement	39.0

The inspection of Table 5-8 shows that the dominant programs are those of ice management and safety, security, and law enforcement. Together with the search and rescue program, these three programs constitute 97 % of the mission activities of the WYTM cutter in the 1st District.

The average evaluation scores of the WYTM class from Table 5-6 have been weighted in proportion to the cutter utilization thru the use of Eq. 5-1.

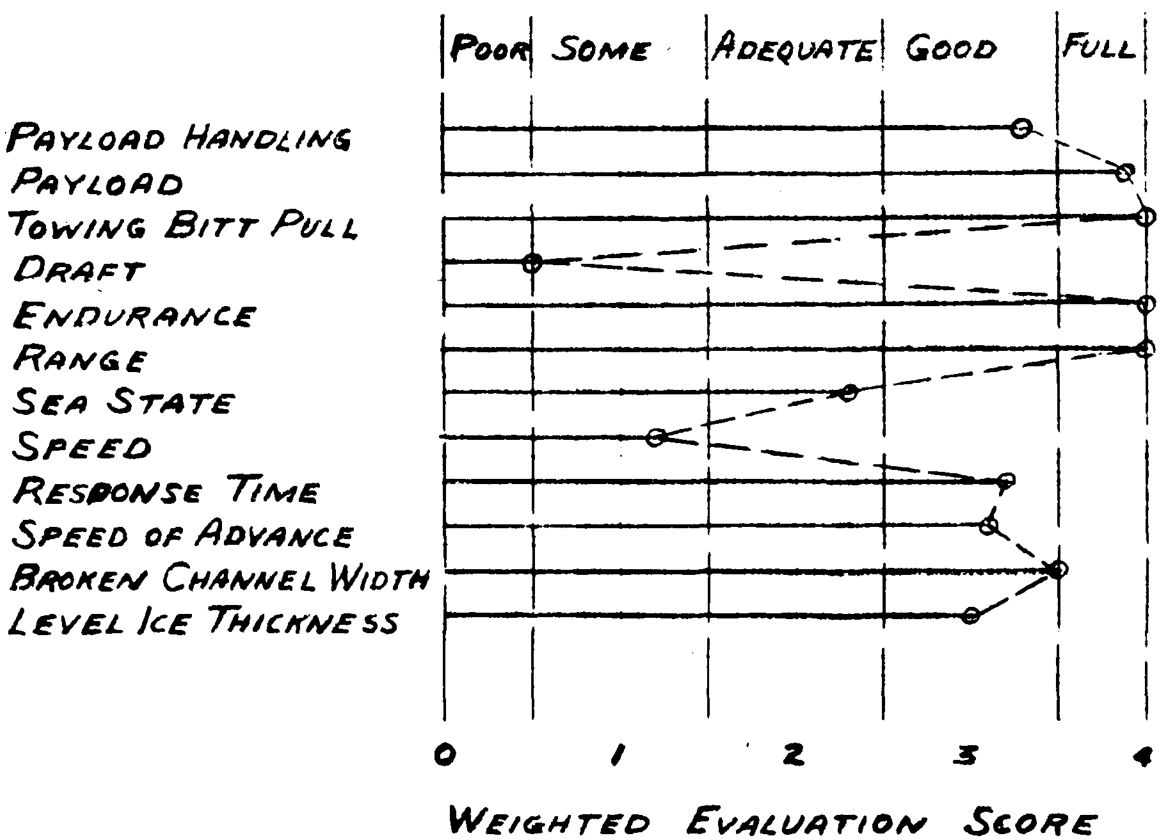
$$S_{avg} = .366\ S_{IM} + .214\ S_{SAR} + .021\ S_{AN} + .008\ S_{EP} + .390\ S_{SSLE} \qquad (5\text{-}1)$$

These weighted average evaluation scores for the twelve vehicle performance evaluation parameters are also listed in Table 5-6.

The profile of Fig. 5-1 provides a picture of the strengths and weaknesses of the WYTM in 1st District employment. The weakest area of the cutter is that pertaining to its draft of 10.5 feet, which precludes its being used in some mission applications across each of the five Coast Guard programs. The next weakest characteristic of the WYTM is that of ship speed. It is considered to constrain the WYTM operations in all program activities, with the exception of the aids to navigation program. In both the draft and speed parameter requirements, the level of the WYTM capability is evaluated at the "some capability" level. It is evident that the operating personnel are of the opinion that improved draft and speed characteristics are of importance.

FIG. 5-1

WYTM PERFORMANCE EVALUATION IN FIRST DISTRICT OPERATIONS



The sea state capability of the WYTM class was also judged to be one of its weaker characteristics, as it received an "adequate capability" rating in this performance category. The performance requirement is stated as a need to operate in seas with a maximum wave height of 20 feet. If the maximum wave height is taken to be the average of the 1/10 highest waves, as is commonly done, the required operating sea state is in the lower end of sea state 6, which is nominally classified as a "high" sea.

In each of the other nine performance areas, the 110 foot WYTM class cutter is judged to provide good to full capability in 1st District operations.

The estimated program utilization of the WTGB class cutters in the Ninth District operations is summarized in Table 5-9.

Table 5-9

Program Utilization of the WTGB in the Ninth District

Program	% Underway Time
Ice Management	50.0 %
Search and Rescue	15.6
Aids to Navigation	0.6
Marine Environmental Protection	2.5
Safety, Security and Law Enforcement	31.3

A review of Table 5-9 indicates that the ice management program is the largest of the program operations in the 9 th District, with the safety, security and law enforcement program being the next most important activity. The search and rescue program, at 15.6 %, is the third most active program. The aids to navigation and marine environmental protection programs initiate

but 3.1 % of the WTGB mission activity.

The average evaluation scores for the WTGB class in Table 5-7 have been weighted in proportion to the cutter utilization thru the use of Eq. 5-2.

$$S_{avg} = .500\ S_{IM} + .156\ S_{SAR} + .006\ S_{AN} + .025\ S_{EP} + .313\ S_{SSLE} \qquad (5\text{-}2)$$

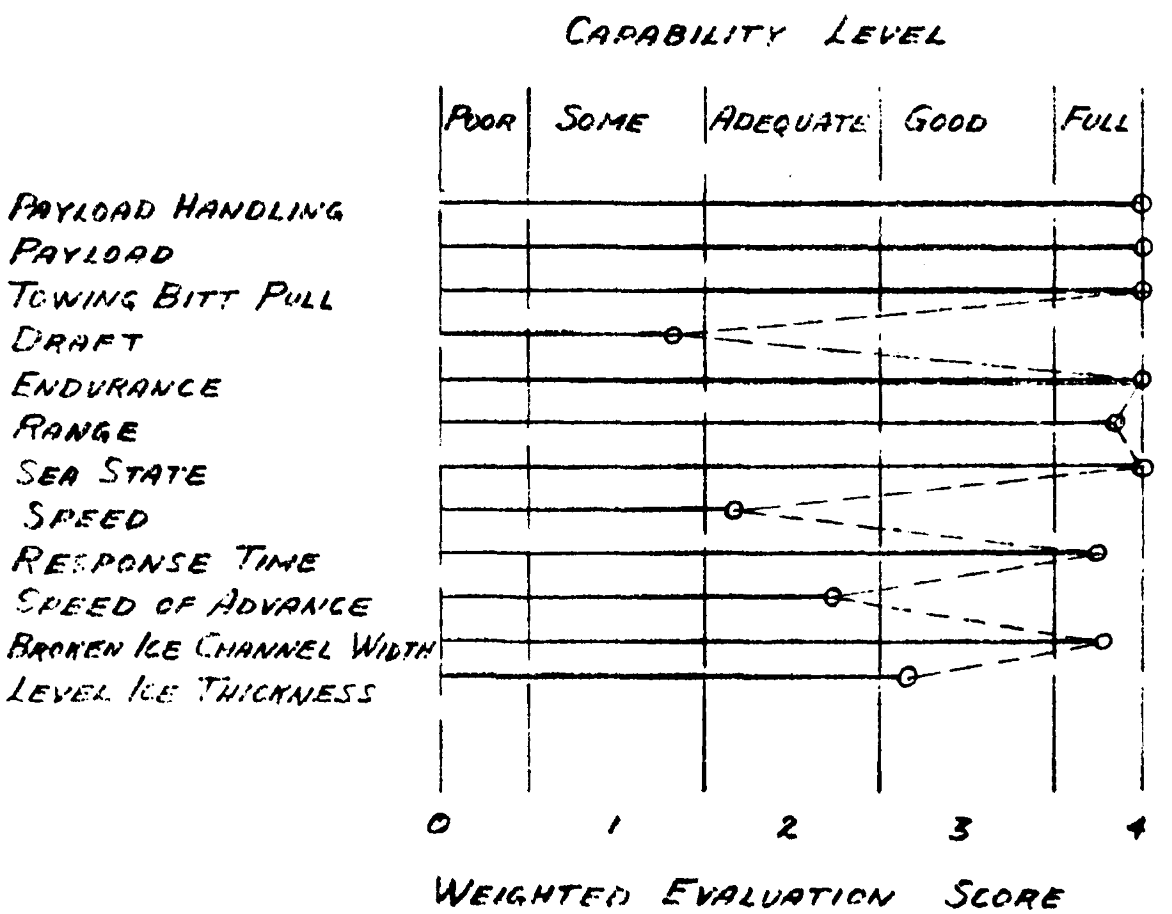
The evaluation profile of Fig. 5-2 provides an indication of the strengths and weaknesses of the WTGB in 9 th District employment. The WTGB draft of 12 feet limits the utilization of the cutter in each of the program areas, and represents the primary weakness of the class. The weighted average rating of 1.3 places the WTGB draft characteristic within the "some capability" category. The cutter speed and speed of advance thru a level ice environment are rated as adequate, and represent the next weakest characteristic of the WTGB.

The increased size and displacement of the WTGB relative to the WYTM give it improved ratings in sea state capability. The near doubling of the freeboard from 3.5 to 6 feet for the WTGB class plays an important role in the improvement of this characteristic relative to the WYTM class cutter.

It should be noted that the icebreaking requirement in the 9 th District is for 4 feet level ice plus ridges. Neither the WTGB nor the Voyageur ACV is capable of meeting this requirement. If this need is of sufficient importance to warrant the supply of equipment to meet it, it would appear that an ACV design will satisfy the requirement more economically than a displacement hull configuration. An icebreaking team which employs an ACV to break the ice and a WTGB class cutter for channel clearing seems worthy of study investigation.

FIG. 5-2

WTGB PERFORMANCE EVALUATION
IN NINTH DISTRICT OPERATIONS



Voyageur ACV Vehicle Evaluation

The Chapter III study has provided a quantitative data base for the evaluation of the Voyageur ACV against the performance requirements which have been defined for the First and Ninth District operations with respect to the icebreaking and open water speed, range, endurance and sea state capability parameters. The ACV evaluation against the performance requirements which have been defined for the First District are presented in Table 5-10. The weighted average scores are presented in Table 5-11 and are profiled in Fig. 5-3 .

The weakest areas of the Voyageur ACV performance characteristics are related to its towing bitt pull and endurance capabilities. In these areas, the ACV is given ratings which fall below the good standard.

The static thrust of the Voyageur with maximum continuous power employed from the two Twinpak engines is approximately 6 300 pounds. This compares with a static thrust level of 21 000 pounds for the WYTM class cutters. There is an obvious advantage with the conventional cutter in this requirement area. The towing bitt pull requirements have been established at 10 tons for the search and rescue, aids to navigation, and safety, security and law enforcement programs, with a 3 ton capability considered to afford a useful vehicle characteristic for the aids to navigation and safety, security and law enforcement program areas. A towing bitt pull of 2 tons is considered to be sufficient for the environmental protection program.

The open water and icebreaking range of the Voyageur ACV meet the stated requirements, but the endurance of 30 hours is considerably less than the 3 - 5 day requirement. There is clearly a relation between the range and endurance requirements, and it is probable that the higher speed of the ACV

Grading System - Full Capability - 4
Good Capability - 3
Adequate Capability - 2
Some Capability - 1
No Capability - 0

VEHICLE EVALUATION AGAINST THE PERFORMANCE REQUIREMENTS FOR THE COAST GUARD TASKS AND MISSIONS

TABLE 5-10

OPERATING TASK	VEHICLE EVALUATION GRADE SCORE FOR THE VOYAGEUR - FIRST DISTRICT (GROUP PORTLAND)											
	Ice Thickness	Ice Channel Width	Speed of Advance	Response Time	Vehicle Speed	Sea State Capability	Range	Endurance	Draft	Towing Bitt Pull	Payload Weight	Necessary Equipment
I Ice Management												
A. Icebreaking												
1. Ports	4	4	4	4	4	3	4	1	4	N/A	N/A	4
2. Waterways	4	4	4	4	4	3	4	1	4	N/A	N/A	4
B. Flood Control												
1. Rivers and Streams	4	4	4	4	4	3	4	1	4	N/A	N/A	4
2. Lakes	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
II Search and Rescue												
A. Establishing Contact	4	4	4	4	4	3	4	1	4	N/A	4	4
B. Providing Assistance												
1. Towing	4	4	1	4	1	0	1	1	4	1	4	4
2. Medical	A/C Used	-	-	-	-	-	-	-	-	-	-	-
3. Mechanical	4	4	1	4	1	3	1	1	4	1	4	4
III Aids to Navigation												
A. Equipment Deployment	4	4	4	4	Not	3	4	4	4	2	3	2
B. Equipment Servicing	4	4	4	4	Critical	3	4	4	4	2	3	2
IV Environmental Protection												
A. Equipment Deployment	4	4	4	4	4	3	4	1	4	4	4	4
B. Area Surveillance	4	4	4	4	4	3	4	1	4	4	4	4
V Safety and Law Enforcement												
A. Inspection and Patrol	N/A	N/A	N/A	4	4	3	3	1	4	2	4	4
B. Interdiction & Apprehension				3	4	3	3	1	4	2	4	4

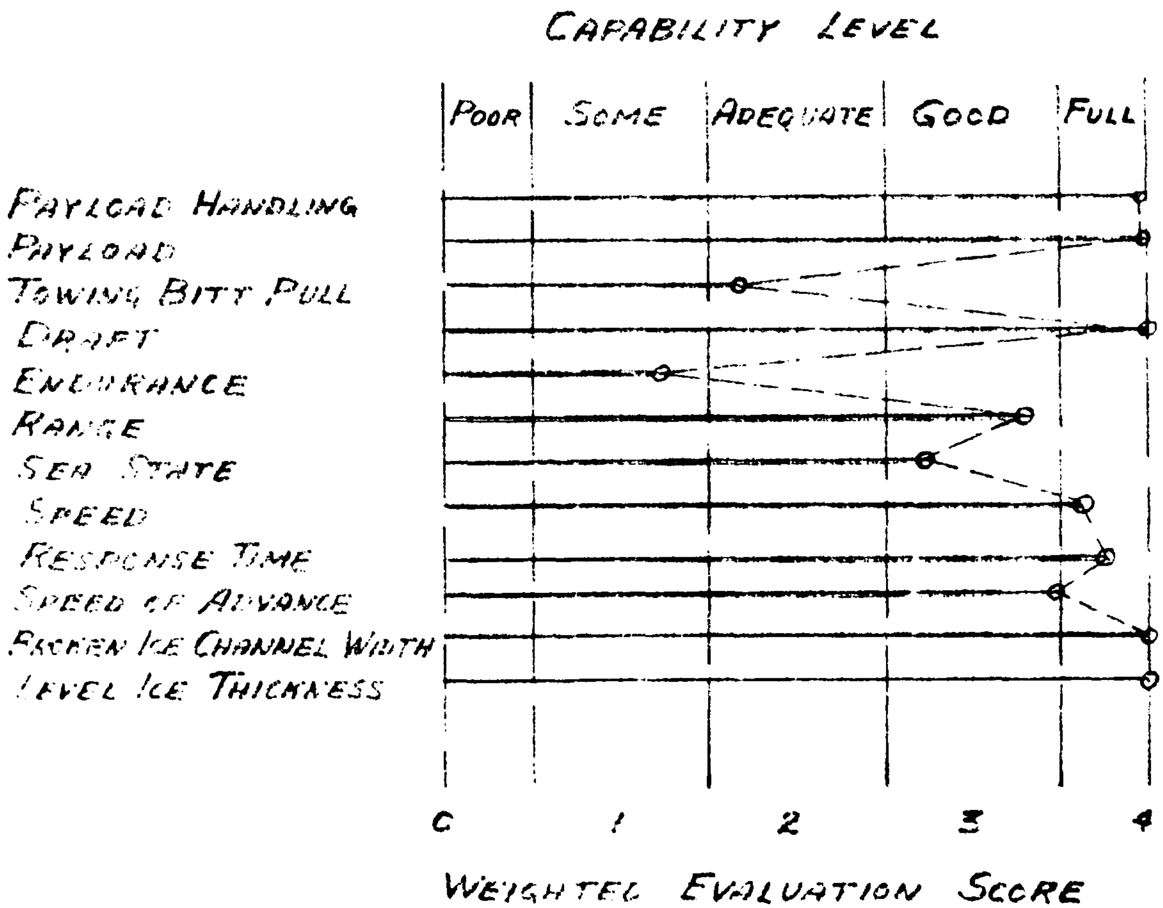
TABLE 5-11

VEHICLE VOYAGEUR ACV DISTRICT FIRST (GROUP PORTLAND)

PERFORMANCE PARAMETER / PROGRAM	AVERAGE EVALUATION SCORE											
	t_{ICE}	ICE CHANNEL WIDTH	SPEED OF ADVANCE	RESPONSE TIME	SPEED	SEA STATE	RANGE	ENDURANCE	DRAFT	TOWING BITT PULL	PAYLOAD	PAYLOAD HANDLING
ICE MANAGEMENT	4.0	4.0	4.0	4.0	4.0	3.0	4.0	1.0	4.0	N/A	N/A	4.0
SEARCH & RESCUE	4.0	4.0	2.5	3.8	2.3	1.8	2.5	1.8	4.0	1.0	4.0	4.0
AIDS TO NAVIGATION	4.0	4.0	4.0	4.0	NOT CRITICAL	3.0	4.0	4.0	4.0	2.0	3.0	2.0
ENVIRONMENTAL PROTECTION	4.0	4.0	4.0	4.0	4.0	3.0	4.0	1.0	4.0	4.0	4.0	4.0
SAFETY, SECURITY & LAW ENFORCEMENT	N/A	N/A	N/A	3.5	4.0	3.0	3.0	1.0	4.0	2.0	4.0	4.0
WEIGHTED AVERAGE	4.0	4.0	3.47	3.76	3.63	2.74	3.29	1.23	4.0	1.68	3.96	3.95

FIG. 5-3

VOYAGEUR ACV PERFORMANCE EVALUATION
IN FIRST DISTRICT OPERATIONS



would result in a lesser endurance requirement for most missions. However, it is clear that the open water range and endurance of an ACV are not competitive with a conventional cutter. The WYTM range at a speed of 10 knots is 3 000 na. mi., resulting in an endurance of 12.5 days. At full speed of 12.5 knots, the WYTM endurance is 8.3 days.

With the exception of the two requirements for towing bitt pull and endurance, the ACV capability is rated as good or full for the remaining ten performance parameters for the First District deployment.

With respect to the 9 th District employment, the Voyageur ACV evaluation scores are presented, averaged and weighted in Tables 5-12 and 5-13. The resulting weighted evaluation profile is shown in Fig. 5-4. The area in which the ACV was evaluated to be the weakest is that of vehicle endurance, in which it was rated as having "some capability". The Voyageur ACV endurance of 30 hours is less than the 2 to 5 day requirement of the Coast Guard programs. The substantially higher speed of the ACV relative to the WTGB in both open water and icebreaking operations may act to reduce the endurance requirements in a number of cases, however.

The towing bitt pull requirement is the next weakest area of the Voyageur ACV. Its thrust of 6 300 pounds is well below the 40 000 pound static thrust of the WTGB class cutter. However, the Voyageur open water towing capability is expected to be sufficient to handle up to a 48 ton boat in tow.

The icebreaking capability of the Voyageur ACV is rated as being marginally good. It does not meet the 4 foot level ice requirement, and is not particularly effective in brash ice. On the other hand, it is capable of breaking over 3 feet of level ice at the open water interface, and can negotiate, and is expected to break, ridges which approach 4 feet in height.

After focusing on the other nine performance requirements, the Voyageur ACV is considered to provide essentially the required levels of capability.

Grading System - Full Capability - 4
Good Capability - 3
Adequate Capability - 2
Some Capability - 1
No Capability - 0

VEHICLE EVALUATION AGAINST THE PERFORMANCE REQUIREMENTS FOR THE COAST GUARD TASKS AND MISSIONS

TABLE 5-12

OPERATING TASK	VEHICLE EVALUATION GRADE SCORE FOR THE VOYAGEUR - NINTH DISTRICT (GROUP SAULT STE. MARIE)											
	Ice Thickness	Ice Channel Width	Speed of Advance	Response Time	Vehicle Speed	Sea State Capability	Range	Endurance	Draft	Towing Bitt Pull	Payload Weight	Necessary Equipment
I Ice Management												
A. Icebreaking												
1. Ports	2	3	Not	4	Not	4	4	1	4	1	4	4
2. Waterways	2	4		4	Critical	4	4	1	4	1	4	4
B. Flood Control			Critical									
1. Rivers and Streams	4	4		4		4	4	1	4	2	4	4
2. Lakes	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
II Search and Rescue												
A. Establishing Contact	2	-	4	4	4	4	4	2	4	—	4	4
B. Providing Assistance												
1. Towing	2	4	1	4	2	4	1	2	4	2	4	4
2. Medical	A/C Used	—	—	—	—	—	—	—	—	—	—	—
3. Mechanical	4	—	N/A	4	2	4	4	2	4	2	4	4
III Aids to Navigation												
A. Equipment Deployment	2	N/A	Not	4	Not	Not Critical	4	3	4	1	4	4
B. Equipment Servicing	2	N/A	Critical	4	Critical	4	4	3	4	1	4	4
IV Environmental Protection												
A. Equipment Deployment	Not	Not	Not	4	Not	4	4	2	4	4	4	4
B. Area Surveillance	Critical	Critical	Critical	4	Critical	4	4	2	4	4	4	4
V Safety and Law Enforcement												
A. Inspection and Patrol	2	N/A	4	Not	4	4	4	1	4	N/A	N/A	N/A
B. Interdiction & Apprehension	2	N/A	4	Critical	4	4	4	1	4	N/A	N/A	N/A

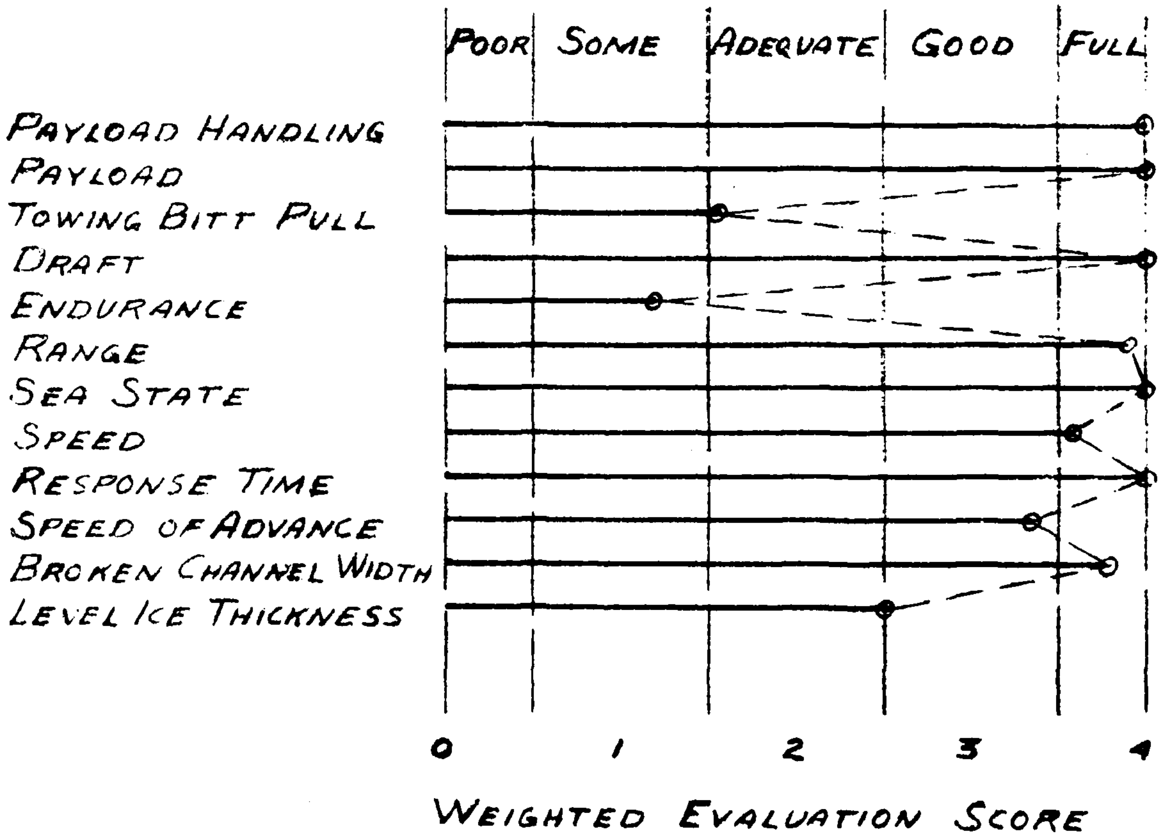
VEHICLE VOYAGEUR ACV   DISTRICT NINTH (GROUP SAULT STE. MARIE)

PERFORMANCE PARAMETER / PROGRAM	AVERAGE EVALUATION SCORE											
	t_{ICE}	ICE CHANNEL WIDTH	SPEED OF ADVANCE	RESPONSE TIME	SPEED	SEA STATE	RANGE	ENDURANCE	DRAFT	TOWING BITT PULL	PAYLOAD	PAYLOAD HANDLING
ICE MANAGEMENT	2.7	3.7	N/C	4.0	N/C	4.0	4.0	1.0	4.0	1.3	4.0	4.0
SEARCH & RESCUE	2.7	4.0	2.0	4.0	2.7	4.0	3.2	2.0	4.0	2.0	4.0	4.0
AIDS TO NAVIGATION	2.0	N/A	N/C	4.0	N/C	4.0	4.0	3.0	4.0	1.0	4.0	4.0
ENVIRONMENTAL PROTECTION	N/C	N/C	N/C	4.0	N/C	4.0	4.0	2.0	4.0	4.0	4.0	4.0
SAFETY, SECURITY & LAW ENFORCEMENT	2.0	N/A	4.0	N/C	4.0	4.0	4.0	1.0	4.0	N/A	N/A	N/A
WEIGHTED AVERAGE	2.51	3.77	3.33	4.0	3.57	4.0	3.88	1.19	4.0	1.55	4.0	4.0

TABLE 5-13

FIG. 5-4

VOYAGEUR ACV PERFORMANCE EVALUATION IN NINTH DISTRICT OPERATIONS



Utilization Analysis

The consideration of ACV deployment to meet the Coast Guard program requirements must include a study of the underway operating hours of the craft over the full year period. To be cost effective, an ACV must be capable of contributing to meeting the Coast Guard program needs during all seasons of the year. In order to initiate an approach to this question, the underway hours of the WYTM class cutters, Snohomish and Yankton, in First District operations for the three year period 1 July 1976 thru 30 June 1979 were reviewed from the cutter Abstract of Operations sheets. Tables 5-14 and 5-15 summarize the three year average quarterly underway operating hours by program area for the two WYTM class cutters. The total underway hours per cutter per year averaged 706 hours. In addition to the five program areas, the underway time which is ascribed to the Logistics and Administrative activities, an internal Coast Guard requirement, is included. Approximately 15 % of the underway time is expended in this area.

Table 5 - 14

Quarterly Operating Hours by Program Area for the Snohomish

3 Year Average for the Years Mid 1976 to Mid 1979

	Quarter				
Program	1st	2nd	3rd	4th	Total
Ice Management	202	0	0	46	248
Search and Rescue	11	7	41	63	122
Aids to Navigation	0	0	0	0	0
Environmental Protection	0	4	3	2	9
Safety, Security & Law Enforcement	0	83	16	48	147
Logistics & Administration	16	73	32	27	148
Total	229	167	92	186	674

Table 5 - 15

Quarterly Operating Hours by Program Area for the Yankton

3 Year Average for the Years Mid 1976 to Mid 1979

	Quarter				
Program	1st	2nd	3rd	4th	Total
Ice Management	199	5	0	1	205
Search and Rescue	11	18	71	19	119
Aids to Navigation	16	2	5	0	23
Environmental Protection	0	0	0	0	0
Safety, Security and Law Enforcement	20	185	83	28	316
Logistics & Administration	30	8	22	13	73
Total	276	218	181	61	736

Using the information developed from the data above, a typical WYTM class underway operating summary for the First District, Table 5-16 , has been prepared. With this as the base data, it now is appropriate to examine the potential utilization of the Voyageur ACV in the First District.

In the estimation of the potential yearly utilization in terms of underway operating hours of the Voyageur ACV in First District employment, the following analytical techniques have been used.

(1) the actual WYTM utilization is established as the base to which incremental underway hours are added or subtracted.

(2) the incremental underway hours which are generated by the high speed and zero draft capabilities of the Voyageur ACV are estimated.

(3) the incremental underway hours which are reduced by the towing bitt pull and endurance capability limitations of the Voyageur are estimated.

TABLE 5-16

VEHICLE ~ WYTM DISTRICT ~ FIRST (GROUP PORTLAND)

MONTHLY UTILIZATION ~ HRS.

TASK	JAN.	FEB.	MAR.	APR.	MAY	JUNE	JULY	AUG.	SEPT.	OCT.	NOV.	DEC.
ICE MANAGEMENT (228)	65	86	50	3	0	0	0	0	0	0	0	24
SEARCH & RESCUE (121)	3	4	4	4	4	5	20	20	16	16	14	11
AIDS TO NAVIGATION (13)	2	3	3	1	0	1	1	1	1	0	0	0
ENVIRONMENTAL PROTECTION (5)	0	0	0	0	1	1	1	0	0	1	1	0
SAFETY & LAW ENFORCEMENT (230)	3	3	4	40	52	40	25	10	15	15	13	10
LOGISTICS & ADMINISTRATION (109)	7	8	8	10	15	15	10	9	8	7	6	6
TOTAL (706)	80	104	69	58	72	62	57	40	40	39	34	51

The increased mission capability and the reduced mission capability of the Voyageur ACV relative to the WYTM in the First District operations are summarized in Table 5-17 , and are related to the five program areas.

At the present time, the WYTM class cutters do very little aids to navigation or marine environmental protection work in the First District. It would appear that a number of mission activities in both these program areas could be handled efficiently by the Voyageur ACV, since it is not draft limited and has a speed capability in the 40 knot range. It is likely that the added capabilities of the ACV will generate additional mission requirements in task areas which are not currently covered because of capability limitations with the existing resources.

Table 5-18 summarizes the incremental, net and total underway hour yearly utilization of the Voyageur ACV relative to the WYTM in the First District. It should be emphasized that the utilization hours of the table represent estimates, not hard data. However, it is believed that the trends which are reflected in this table are representative of future operational potential.

Table 5 - 18

Yearly Underway Hour Estimates for the Voyageur ACV in the First District

Program	Hours Added	Hours Subtracted	Net Change	Total
Ice Management	190	0	190	418
Search and Rescue	40	20	20	141
Aids to Navigation	100	0	100	113
Marine Environmental Protection	50	0	50	55
Safety, Security and Law Enforcement	150	50	100	330
Logistics and Administration	0	0	0	109
Total	530	70	460	1 166

Table 5 - 17

Incremental Mission Capability of the Voyageur ACV Compared With the WYTM Class Cutter in the First District

Program	Added Mission Capability	Reduced Mission Capability
Ice Management	1. Shallow water icebreaking, e.g. fishing vessel breakout 2. Flood control icebreaking in shallow water 3. Can break level ice of 2 foot thickness	1. Produces a wide broken ice channel instead of a narrow, clear channel in the ice
Search and Rescue	1. Shallow water assistance 2. Improved response time to calls with greater productivity	1. Reduced towing capability, towed vessel size limited to approximately 48 tons 2. Mission duration limited to 1 - 2 days
Aids to Navigation	1. Low tide, shallow water servicing and deployment of aids 2. Greater productivity due to higher transit speed 3. Can service light stations over the ice	1. Reduced towing bitt pull capability, approximately 6 000 lbs.
Marine Environmental Protection	1. Shallow water operational capability 2. Quick reaction to incidents and extended surveillance capability	1. Unrefueled mission endurance limited to 1 - 2 days
Safety, Security and Law Enforcement	1. Low tide, shallow water operational capability 2. Ability to interdict and apprehend high speed violators	1. Reduced towing bitt capability, towed vessel size limited to approximately 48 tons 2. Unrefueled mission endurance limited to 1 - 2 days

TABLE 5-19

VEHICLE ~ ACV

DISTRICT ~ FIRST (GROUP PORTLAND)

MONTHLY UTILIZATION ~ HRS.

TASK	JAN.	FEB.	MAR.	APR.	MAY	JUNE	JULY	AUG.	SEPT.	OCT.	NOV.	DEC.
ICE MANAGEMENT (418)	105	146	100	23								44
SEARCH & RESCUE (141)	3	4	4	4	4	10	25	25	21	16	14	11
AIDS TO NAVIGATION (113)	6	6	6	10	12	12	12	12	12	10	9	6
ENVIRONMENTAL PROTECTION (55)	0	0	0	6	7	7	7	7	7	7	7	0
SAFETY & LAW ENFORCEMENT (330)	5	5	10	50	60	55	35	25	25	25	20	15
LOGISTICS & ADMINISTRATION (109)	7	8	8	10	15	15	10	9	8	7	6	6
TOTAL (1166)	126	169	128	103	98	99	89	78	73	65	56	82

The net increase in underway operating hours is estimated as 460 hours per year, with the bulk of the increase coming in the ice management, aids to navigation, and safety, security and law enforcement programs. The removal of draft limitations and the increased speed of the ACV open new application potential in each of the three program areas. The total underway hour utilization of 1 166 hours per year is well within the ACV capabilities. Table 5-19 shows the expected underway hour distribution by month over the yearly period.

Ninth District Utilization

The utilization estimates for the WTGB class cutters in the Ninth District was developed from an analysis of the Abstracts of Operations for the Katmai Bay, WTGB-101, Ref. 11, and the Ref. 12 letter from the Sault Ste. Marie Group Commander and are shown in Table 5-20.

The Group assessment of the WTGB utilization is at an annual underway operating hour level of 1 720 hours. The dominant mission is that of ice management, with approximately half of the work of the cutter being involved in this program. The assisting of commercial carriers thru the brash ice of the St. Marys River between Lakes Superior and Huron is an important part of the ice management activity in the Ninth District.

The safety, security and law enforcement program duties provide the next heaviest demand upon the cutter. This is primarily a requirement of the summer season when ice is not a factor.

The search and rescue case load for the WTGB is at the level of 15 - 20 cases per year, each of which requires a mission length between 12 and 36 hours.

TABLE 5-20

VEHICLE ~ WTGB DISTRICT ~ NINTH (GROUP SAULT STE. MARIE)

MONTHLY UTILIZATION ~ HRS.

TASK	JAN.	FEB.	MAR.	APR.	MAY	JUNE	JULY	AUG.	SEPT.	OCT.	NOV.	DEC.
ICE MANAGEMENT (800)	240	240	200	60								60
SEARCH & RESCUE (250)					30	60	70	60	30			
AIDS TO NAVIGATION (10)				2	2	2	2	2				
ENVIRONMENTAL PROTECTION (40)				4	5	5	6	6	5	5	4	
SAFETY & LAW ENFORCEMENT (500)				30	70	90	110	100	70	30		
LOGISTICS & ADMINISTRATION (120)	5	5	5	10	15	15	15	15	15	10	5	5
TOTAL (1720)	245	245	205	106	122	172	203	183	120	45	9	65

The aids to navigation and marine environmental protection program applications are expected to provide a relatively minor level of dema for WTGB services.

In the logistics and administration area of activity, a demand which is similar to that placed upon the WYTM class cutter in the First District has been predicted.

The utilization estimates for the Voyageur ACV in the Ninth District have been made with the same analytical procedure as was employed previously in the First District study. The incremental mission capability of the Voyageur ACV compared with the WTGB class cutter is summarized in Table 5-21 for the Coast Guard programs.

To a large extent, the incremental capabilities of the Voyageur for Ninth District operations are similar to those which have been studied for the First District operations. One specific consideration is worthy of mention, however. An ACV icebreaker is relatively ineffective in brash ice, and as has been previously noted, this is a major environmental factor in the St. Marys River.

Table 5-22 summarizes the incremental underway operating hours which are estimated for the Voyageur ACV relative to the WTGB class cutters in Ninth District operations.

The net increase in underway operating hours of the Voyageur ACV is estimated as 170 hours per year, relative to the utilization of the WTGB. A loss of 300 hours is estimated to result from the ACV limitations in brash ice operations. However, 200 hours are estimated to be used in shallow water and flood control icebreaking missions which are not possible with the WTGB. The Voyageur ACV has also broken level ice of a thickness in excess of 3 feet at the open water edge of an ice sheet in Canadian operations.

AD-A084 923 DECKER (J L) POTOMAC MD F/G 13/10
A FEASIBILITY STUDY OF AIR CUSHION VEHICLE UTILIZATION IN COAST--ETC(U)
APR 80 J L DECKER DOT-CG-933571-A
UNCLASSIFIED USCG-D-25-80 NL

2 OF 2
ADA
084923

END
DATE
FILMED
7-80
DTIC

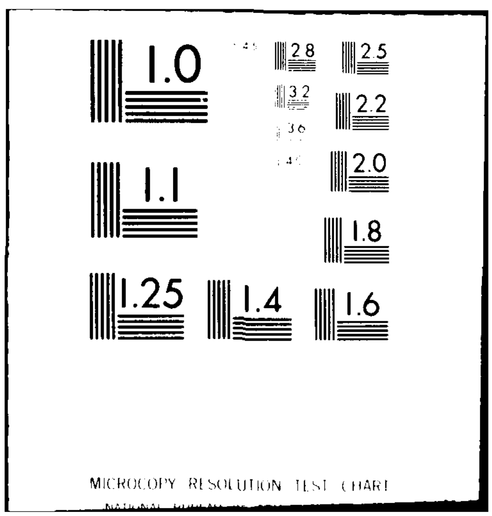

1.0
2.8
2.5
3.2
2.2
3.6
2.0
1.1
1.8
1.25
1.4
1.6
MICROCOPY RESOLUTION TEST CHART

Table 5 - 21

Incremental Mission Capability of the Voyageur ACV Comapred With the WTGB Class Cutter in the Ninth District

Program	Added Mission Capability	Reduced Mission Capability
Ice Management	1. Shallow water icebreaking 2. Flood control icebreaking in shallow water 3. Can break over 3 feet of level ice at its open water edge	1. Relatively ineffective in brash ice, except in the breaking of refrozen brash
Search and Rescue	1. Shallow water assistance 2. Improved response time to calls with greater productivity	1. Reduced towing capability, towed vessel size limited to approximately 48 tons.
Aids to Navigation	1. Shallow water servicing and deployment of aids 2. Greater productivity due to higher transit speed 3. Can service light stations over the ice	1. Reduced towing bitt pull capability, approximately 6 000 lbs.
Marine Environmental Protection	1. Shallow water operational capability 2. Quick reaction to incidents and extended surveillance capability	1. Unrefueled mission endurance limited to 1 - 2 days
Safety, Security and Law Enforcement	1. Shallow water operational capability 2. Ability to interdict and apprehend high speed violators	1. Reduced towing bitt pull capability, towed vessel size limited to approximately 48 tons 2. Unrefueled mission endurance limited to 1 - 2 days

Table 5 - 22

Yearly Underway Hour Estimates for the Voyageur ACV in the Ninth District

Program	Hours Added	Hours Subtracted	Net Change	Total
Ice Management	200	300	- 100	700
Search and Rescue	40	20	20	270
Aids to Navigation	100	0	100	110
Marine Environmental Protection	50	0	50	90
Safety, Security and Law Enforcement	200	100	100	600
Logistics and Administration	0	0	0	120
Total	+ 590	- 420	+ 170	1 890

The ability of the ACV to operate in shallow water, together with its high transit speed is predicted to generate an additional 100 hours of aids to navigation applications. The same factors should result in added utilization in the marine environmental protection and safety, security and law enforcement programs.

A study of three years of search and rescue operations which were conducted by the Ninth District stations during the years 1967 - 69, revealed that a total of 9 214 search and rescue missions were performed. See Ref. 13 . Of these operations, approximately 94 % were involved in providing assistance to boats of 32 feet in length or smaller. The displacement of such small craft does not exceed 7 tons. Towing assistance was required in 5 237 cases, or in 56.8 % of the incidents. If a criterion is applied for the required towing force to be 5 % of the towed craft weight, a tow force requirement of 750 pounds emerges for the 32 foot boats. As a reference point, the thrust to weight ratio of the WTGB is 0.028. With a thrust level at continuous power of 6 000 pounds, the Voyageur ACV would appear to have ample thrust margin to tow a 32 foot boat.

Using a tow thrust to weight ratio of 0.028, and reserving one half of the Voyageur thrust for the ACV itself, it would appear to be feasible for the Voyageur to tow a boat of 48 tons displacement.

In summary, the icebreaking, zero draft, and high speed capabilities of an ACV such as the Voyageur are expected to develop a Coast Guard utilization which is more extensive than that of the existing Coast Guard cutters. The expected utilization of the Voyageur in the Ninth District is presented in Table 5-23.

TABLE 5-25

VEHICLE ~ ACV

DISTRICT ~ NINTH (GROUP SAULT STE. MARIE)

MONTHLY UTILIZATION ~ HRS.

TASK	JAN.	FEB.	MAR.	APR.	MAY	JUNE	JULY	AUG.	SEPT.	OCT.	NOV.	DEC.
ICE MANAGEMENT (700)	170	180	180	90								80
SEARCH & RESCUE (270)					30	60	80	70	30			
AIDS TO NAVIGATION (110)	5	5	5	10	12	12	12	12	12	10	9	6
ENVIRONMENTAL PROTECTION (90)				10	12	12	12	12	12	10	10	
SAFETY & LAW ENFORCEMENT (600)				40	90	100	120	120	90	40		
LOGISTICS & (120) ADMINISTRATION	5	5	5	10	15	15	15	15	15	10	5	5
TOTAL (1890)	180	190	190	160	157	197	239	229	159	70	24	91

VI OPERATING COST ANALYSIS

The operating costs of the Voyageur ACV will be determined as the sum of four primary cost elements.

- Capital Charges or Depreciation
- Maintenance
- Crew
- Fuel

These four cost elements are analyzed on the basis of total operating cost per operating hour and also with respect to the annual operating cost of the ACV in this chapter of the study. January 1980 prices will be employed herein.

ACV Capital Charge

At the end of January 1980, the following vehicle acquisition information was made available by the Voyageur ACV manufacturer.

Table 6 - 1

Voyageur ACV Acquisition Data as of 30 January 1980

Craft Status	Price	Delivery Span Time
Used - Voyageur No. 3 and 4 with new skirts and rebuilt engines	$2 130 000	6 to 8 mo.
New	4 500 000	12 to 18 mo.

Data Source: Telecon from Mr. William Johnson, Bell Aerospace Company

In view of the fact that a Coast Guard decision to purchase an ACV is not imminent, Coast Guard direction was provided to conduct the cost study

on the basis of the procurement of a new Voyageur.

The estimated breakdown of the acquisition price of a new Voyageur by major subsystem is presented in Table 6 -2.

Table 6 - 2

<u>Estimated Subsystem Price Breakdown for the Voyageur</u>

Subsystem	Total Price	Parts Cost
Structure	$ 1 162 650	$ 694 950
Lift and Propulsion	2 681 250	1 602 600
Skirt	261 750	156 510
Auxiliary	394 350	235 730
Total	4 500 000	2 689 790

The price breakdown of Table 6 -2 is important in the analysis of the maintenance costs which are related to the various craft subsystems.

The utilization of the Voyageur ACV in the First District is estimated to be 1 166 operating hours per year, and in the Ninth District as 1 890 operating hours per year. Due to the substantial difference in expected utilization between the two districts, a 30 year vehicle operating lifetime is projected for First District operations, and a 20 year vehicle operating lifetime is utilized for the Ninth District operations. The annual and hourly charges allocated to capital consumption (depreciation) for the Voyageur ACV are shown in Table 6 -3. These charges are consistent with straight line, rather than, accelerated capital consumption calculation methods.

Table 6 - 3

<u>Voyageur ACV Capital Charges</u>

District	Annual Charge	Hourly Charge
First	$ 150 000 /yr.	$ 128.64 /hr.
Ninth	225 000	119.05

Voyageur ACV Maintenance Costs

The total maintenance expenditures for the Voyageur ACV will be estimated as the sum of two major elements, the cost of maintenance labor and the cost of the parts which are utilized in the maintenance activities. The Voyageur maintenance labor expenditures will be estimated from a consideration of the Canadian Coast Guard winter icebreaking operations with the Voyageur as reported in Ref. 7. The data of Table 6-4 summarize the maintenance labor experience which is detailed in the reference.

Table 6 - 4

Voyageur Maintenance Manhours - Canadian Coast Guard Operations
January - March 1976

ACV Operating Hours	126 hrs.
Routine Maintenance Labor	314.5 man hrs.
Repair Maintenance Labor	692.5 man hrs.
Total Maintenance Labor	1 007 man hrs.
Repair Maintenance Labor - Skirt	504.5 man hrs.
Total Maintenance Labor - Less Skirt Repair	502.5 man hrs.

It may be observed from Table 6-4 that the skirt repair maintenance accounted for half of the total maintenance labor effort, and 73 % of the total craft repair labor requirements. The skirt on the Voyageur at the outset of the test period was approximately 2½ years old, and had previously been subjected to extensive usage and extremes in temperature and weather. The skirt material had incurred significant deterioration from its age and previous operational usage. Consequently, the forward and side areas of the peripheral skirt were replaced during the middle of the operating period in

the month of February. Following the partial skirt replacement, the required skirt maintenance was essentially eliminated for the balance of the operating period.

Over the three month utilization of 126 operating hours, the following maintenance labor requirements may be developed:

Total ACV Maintenance less Skirt	3.99 MH/OH
Skirt Maintenance	4.00 MH/OH
Total ACV Maintenance following Skirt Repair	3.6 MH/OH

On the basis of this Voyageur maintenance labor experience, it is appropriate to utilize the following maintenance labor requirements for the operations of the Voyageur ACV.

Total ACV Maintenance less Skirt	4.0 MH/OH
Skirt Maintenance	2.0 MH/OH

The maintenance labor requirements of the skirt have been chosen to reflect an average condition between that of a new skirt, and that of a used skirt shortly before its necessary replacement. It should be noted that the total craft maintenance experience of the Canadian Coast Guard , following the partial replacement of the skirt, was 3.6 MH/OH, a figure which is 10 % less than the craft less skirt maintenance manhour level which is to be employed herein for cost analysis purposes.

The Voyageur skirt was not designed to suppress spray, and considerable maintenance labor effort was required in the winter icebreaking operations of the Canadian Coast Guard for the deicing of the ACV between operational sorties. This deicing effort was at the level of:

Deicing Maintenance	2.48 MH/OH

Spray suppressing skirts have been designed and operated effectively on several ACV designs. Consequently, it would appear that the labor hours required for the deicing of the Voyageur may be significantly reduced from the 2.48 MH/OH level.

The basic maintenance labor manhour requirements of the Voyageur are estimated as 6.0 MH/OH, with the distribution of the maintenance effort as shown in Table 6 - 5 .

Table 6 - 5

Estimated Voyageur ACV Maintenance Labor Requirements

Sub-system	Maintenance MH/OH
Structure	0.35
Lift and Propulsion	2.00
Skirt	2.00
Auxiliaries	1.65

In addition to the maintenance labor, the cost of the maintenance parts and material must be included in a maintenance analysis. Since an adequate data base for the Voyageur is not available to the author, it is appropriate to work from an analysis of 5 000 hours of actual Bell SK-5 operations which are reported in Ref. 11, in order to establish a basis for the maintenance material cost of the Voyageur ACV. From the presentation in Tables B-1-A and B-1-B of this reference, overhaul factors and parts cost data have been grouped and are summarized in Table 6 - 6 which follows.

Table 6 - 6

Bell SK-5 Maintenance Parts Usage Summary Based Upon 5 000 Hours of ACV Operations

Subsystem	Parts Cost	Parts Replacement Cost	Weighted Over-haul Factor	Maintenance Parts Cost
Structure	$ 120 000*	$ 0.35 per hr.	1.00	$ 0.35 per hr.
Lift and Propulsion	186 119	100.43	0.235	23.60
Skirt	33 337	5.27	1.00	5.27
Auxiliary	31 539	13.83	0.175	2.42
Total	$ 370 995	119.88	-	31.64

* Estimated

During the U.S. Coast Guard operational tests of the SK-5 which were conducted within the second half of 1972, a total of 361.7 operating hours were utilized with two ACV. The actual maintenance parts costs are compared with the projections developed from Table 6-6 in the presentation of Table 6 - 7 .

Table 6 - 7

Comparison of the Actual Maintenance Parts Cost During 1972 U.S. Coast Guard ACV Test Program with the Cost Projected from 5 000 Hours of Bell SK-5 Operations

Subsystem	Actual Parts Cost 1972 USCG Tests	Projected Parts Costs 5 000 hrs of SK-5 Use
Structure	$ 125	$ 127
Lift and Propulsion	11 688	8 536
Skirt	120	1 906
Auxiliary	3 770	875
Total	$ 15 703	$ 11 444

Included in the actual maintenance parts costs of the USCG tests was \$ 11 000 for the replacement of a No. 1 gearbox in the transmission system. This gearbox has an expected failure rate of 0.00036 per hour, giving an expected mean time between failure of 2 778 hours. This results in a probability of failure of 12.2 % during the 361.7 operating hour period of the 1972 USCG test program. An expected maintenance parts cost of \$ 1 342 for the test period is predicted. A major failure of this type would be averaged out over a substantially larger operating hour sample. If the No. 1 gearbox failure is removed from the data sample, the actual replacement parts cost of \$ 4 703 compares with a projected value of \$ 10 102. Therefore, the maintenance parts cost of the ACV less the No. 1 gearbox was considerably less than the projected value during these 1972 USCG ACV tests with craft which were 7 years old and with Vietnam usage behind them. In summary, it appears that the maintenance parts cost data of Table 6 - 6 provide a reasonable estimate of this parameter for the SK-5 ACV.

It is now necessary to be able to adapt the maintenance parts cost data from the SK-5 for use in the Voyageur analysis. In order to accomplish this end, it is appropriate to employ the concept of the maintenance lifetime used by the author in Ref. 6. The maintenance lifetime is defined as

> the number of vehicle operating hours at which the maintenance costs are equal to the acquisition cost of the equipment.

This concept may be applied to the maintenance parts cost, maintenance labor cost or the total maintenance cost of a major subsystem or a complete vehicle system. It should be clearly recognized that the total cost of a subsystem or vehicle is considerably larger than the cost of the parts which comprise the configuration. This is necessarily true to account for the expenses which are incurred in design, test, assembly, transport, financing, and the many other expenses which are necessary to the delivery of an end product.

The parts maintenance lifetime values for the four major subsystems of the SERV (SK-5) are listed in Table 6 - 8 .

Table 6 - 8

ACV Parts Maintenance Lifetime Based Upon 5 000 Hours of Bell SK-5 Operations

Subsystem	Parts Maintenance Lifetime - hrs.
Structure	340 000
Lift and Propulsion	7 890
Skirt	6 325
Auxiliary	13 030

The structures subsystem has the largest value of the parts maintenance lifetime at 340 000 hours, while the skirt has the smallest parts maintenance lifetime at 6 325 hours. It is assumed that the values of the parts maintenance lifetime which have been developed for the SK-5 usage over 5000 operating hours of the craft are applicable to the Voyageur. This policy is considered to be a conservative action, particularly with respect to the structure, since the Voyageur hollowcore construction is very much more rugged than the thin gage material used in the SK-5 ACV.

The subsystem acquisition and parts costs for the Voyageur ACV which were developed in Table 6-2 may be combined with the ACV parts maintenance lifetime values given in Table 6-8 to develop the cost of the maintenance parts per operating hour of the craft. These results are shown in Table 6-9.

Table 6 - 9

Maintenance Parts Costs for the Voyageur ACV

Subsystem	Subsystem Cost	Parts Cost	Parts Maintenance Lifetime	Maintenance Parts Cost per OH
Structure	$ 1 162 650	$ 694 950	340 000 hrs	$ 2.04
Lift and Propulsion	2 681 250	1 602 600	7 890	203.12
Skirt	261 750	156 510	6 325	24.74
Auxiliaries	394 350	235 730	13 030	18.09
Total	$ 4 500 000	$ 2 689 790	10 846	$ 248.00

The total maintenance parts cost of $ 248 per hour is dominated by the lift and propulsion, which contributes 82 % of the total expense of the maintenance parts. The maintenance labor costs will be addressed within the personnel costs of the Voyageur ACV unit.

Voyageur ACV Unit Personnel Complement

The proper structuring of the ACV unit personnel complement with respect to both the number of men and their skills is of major importance to the successful operation of the ACV in the programs of the U.S. Coast Guard. In the examination within this study, it is assumed that the ACV will be operated from an active Coast Guard base which possesses the required support capabilities in terms of work shops and storage facilities, transportation vehicles, and the clerical assistance which are normally present at Coast Guard installations.

The recommended unit personnel complement for the Voyageur in Coast Guard employment is presented in Table 6 - 10 . The unit is commanded by an Officer-in-Charge who is also capable of functioning as the ACV command pilot. It is recommended that a total of four members of the unit be qualified to operate the ACV. The maximum expected ACV utilization of 239 hours per month in the summer (9 th District) is sufficient to require a relief crew to function in the pilot and co-pilot/navigator positions which comprise a two man ACV operator team. Dual controls are installed in the Voyageur, so that either of the two positions may be used for the craft operation.

An eight man support crew for the maintenance and operational support functions is recommended. Of this group, four men are to be well qualified ACV maintenance personnel. Three of the four are to be fully qualified in one or more of the following maintenance specialties:

- Lift and Propulsion
- Electrical/Electronics
- Structure/Skirt

in order that the ACV maintenance requirements are fully covered. The fourth

man, the lead hand, should be an experienced technician who is capable of maintenance trouble shooting and repair.

Four crewmen are included in the unit to provide the maintenance and operating support which is required. It is obviously desirable to select the crewmen from candidates with the talent and desire to progress to increased responsibility levels in the maintenance or operations of the Coast Guard ACV.

Table 6 - 10

Recommended USCG Voyageur Unit Personnel Complement

No. of Men	Function	Job Description
1	Officer in Charge	Unit Commander, also serves as ACV command pilot.
2	First Pilot	ACV Pilot in relief of Unit Commander; serves as co-pilot and navigator when Unit Commander is operating the ACV.
1	Second Pilot	Serves as co-pilot and navigator.
1	Lead Maintenance Engineer	Responsible for the ACV maintenance. Must be fully qualified in either the lift and propulsion, electrical/electronics, or the structures/skirt subsystems maintenance activities.
2	Maintenance Engineer	Each man must be fully qualified in a maintenance specialty to complement the lead maintenance engineer.
1	Lead Hand	Works on maintenance tasks under the direction of the Lead Maintenance Engineer.
4	Crewmen	Assist the more senior personnel in the operations and maintenance efforts.

The winter operations of the Voyageur ACV in the Ninth District are projected to develop a maximum of 190 operating hours per month. A total of 1 611 maintenance manhours per month are estimated to be required at this level of operations, using the 6 MH/OH maintenance projection which has been developed herein, and including a 2.48 MH/OH deicing requirement. This allocation for ACV deicing reflects the Canadian Coast Guard experience with the Voyageur during the winter of 1976. It is recommended that the Voyageur be equipped with a skirt design which suppresses the spray generated by the cushion air exiting beneath the craft skirt. Spray suppression skirt designs are available and have proven to be effective. Consequently, it should be possible to reduce substantially the deicing maintenance manhour requirements. However, if the 1 611 maintenance manhour requirement is satisfied by the 8 man maintenance crew, 28.1 hours of overtime per man per month is necessary during the two months of maximum winter season ACV utilization.

During the summertime peak of 239 operating hours per month, a total of 1 434 maintenance manhours per month are needed. For this single month peak of operational activity, the 8 man maintenance crew will be required to work 5.9 hours of overtime per man.

The six months which include April, May, and the September thru December period are expected to demand considerably lower utilization levels of the Voyageur ACV, thereby making it possible for the Voyageur unit personnel to take leave and balance the periods in which their work load is heavy.

The Canadian Coast Guard operated the Voyageur in the winter of 1976 with a unit complement of 7 men, with the peak operating rate of 82.4 ACV operating hours per month. It would appear that the recommended Voyageur ACV unit complement is consistent with the CCG experience with the vehicle.

The foregoing analysis of the required Voyageur ACV unit personnel complement has been developed for Ninth District operations with an expected

craft utilization of 1 890 operating hours per year. In the First District, the expected utilization of 1 166 hours per year may make possible a reduction in the number of maintenance personnel. The February winter peak of 169 operating hours per month requires 1 415 maintenance man hours per month, including 419 hours for the craft deicing maintenance. An average overtime of 19.4 hours per month per man is required of an 8 man maintenance crew during this short month of peak activity. The summertime maintenance load peaks at 594 maintenance manhours per month, and may be met with a four man maintenance crew. If it is feasible from the personnel management considerations, it appears desirable to augment a basic five man maintenance team with three additional personnel for the January thru March period in the First District operations of the Voyageur ACV.

Voyageur ACV Unit Personnel Costs

The Voyageur ACV unit is comprised of both operating and maintenance personnel. A representative breakdown of the unit personnel and the associated annual compensation costs is shown in Table 6 - 11. The data of this table are consistent with the skill requirements which were summarized in Table 6 - 10.

Table 6 - 11

Voyageur Unit Personnel Costs - FY 82

Operating Crew

Grade	No. of Men	Annual Pay Per Man	Total Annual Pay
Lieutenant	1	$ 25 200	$ 25 200
Chief Warrant Officer	1	23 600	23 600
Warrant Officer	2	23 600	47 200
Total	4		$ 96 000

Table 6 - 11 Continued

Maintenance Crew

Grade	No. of Men	Annual Pay Per Man	Total Annual Pay
Chief Petty Officer	1	$ 18 400	$ 18 400
Petty Officer - 1st	2	15 700	31 400
Petty Officer - 3rd	1	11 400	11 400
Seaman	4	8 800	35 200
Total	8		$ 96 400
Total	12		$ 192 400

The Voyageur ACV unit personnel expenses are allocated to the operating and maintenance functions in Tables 6-12 and 6-13. These allocations are developed for the First and Ninth District operations in these two tables.

Table 6 - 12

Voyageur ACV Operating Crew Expenses

District	Annual Expense	Cost/Operating Hour	Annual Operating Hours
First	$ 96 000	$ 82.33	1 166
Ninth	96 000	50.79	1 890

Table 6 - 13

Voyageur ACV Maintenance Crew Expenses

District	Annual Expense	Cost/Operating Hour	Annual Operating Hours
First	$ 96 400	$ 82.68	1 166
Ninth	96 400	51.01	1 890

Voyageur ACV Fuel Costs

During the 1972 U.S. Coast Guard ACV operational test program, reported in Ref. 11, the fuel consumption over the 361.7 hours of ACV operations averaged 41 gallons per hour. It is reasonable to assume that the average fuel usage of the Voyageur in non-icebreaking operations may be estimated with this value as a base and with the assumptions:

(1) the fuel consumption is proportional to the ACV weight

(2) the Voyageur and SK-5 average speeds are comparable

(3) the powerplant and propulsor efficiencies are comparable

The weight ratio of the Voyageur to the SK-5 is 4.4 to 1, so it is projected that the average fuel consumption of the Voyageur in the summertime operations is 180 gallons per hour. For reference purposes, this approximates an average operating power level of 750 HP for each of the Pratt and Whitney of Canada Twinpak engines. This power level is in the range of 55 % of the normal rated power of the engine. The typical price of JP-5 gas turbine fuel to the government in January 1980 is 84¢ per gallon. At this price level, the fuel cost of the Voyageur is $151.20 per operating hour.

Wintertime icebreaking operations will normally require a higher average level of engine horsepower. If the operating power level is estimated as 1 040 HP for each of the two powerplants, the fuel consumption of the Voyageur ACV is 215 gallons per hour. As the engine horsepower is increased from 750 to 1 040, the rate of fuel usage does not increase proportionately, since the specific fuel consumption of the engines drops approximately 15 %. The cost of fuel for the wintertime icebreaking operations of the Voyageur is estimated as $ 181 per hour.

The Voyageur ACV gas turbine powerplants burn JP-5 fuel, in contrast to the diesel fuel which is used in the WYTM and WTGB classes of Coast Guard cutters. The average price of 84 cents per gallon to the Government in January 1980 for the JP-5 compares with the Government purchase price of 79 cents per gallon for the diesel fuel. On this basis, the diesel fuel cost per gallon is 94 % of that of the JP-5.

These fuel prices were obtained in a telecon with Maj. D. Peschka of the DFSC on 30 January 1980.

Voyageur ACV Total Operating Costs

The cost data which have been developed in the foregoing sections may be summarized to determine the total operating cost of the Voyageur ACV in Coast Guard operations. This summary is presented in Tables 6-14 and 6-15, for the First and Ninth District operations of the craft.

Table 6 - 14

Voyageur ACV Operating Costs in the First District

Item	Annual Cost	DOC/OH		
Capital Charge	$ 150 000		$ 128.60	(18.2%)
Maintenance	385 568		330.68	(46.7)
Parts $ 289 168		$ 248.00		
Labor 96 400		82.68		
Operating Crew	96 000		82.33	(11.6)
Fuel	193 566		166.00	(23.5)
Total	825 134		707.61	

Notes: (a) Operating Lifetime = 30 yrs. (b) Fuel Price = $0.84 /gal.

Table 6 - 15

Voyageur ACV Operating Costs in the Ninth District

Item	Annual Cost	DOC/OH		
Capital Charge	$ 225 000		$ 119.10	(18.8%)
Maintenance	565 120		299.01	(47.1)
Parts $ 468 720		$ 248.00		
Labor 96 400		51.01		
Operating Crew	96 000		50.79	(8.0)
Fuel	313 740		166.00	(26.1)
Total	$ 1 199 860		$ 634.90	

Notes: (a) Operating Lifetime = 20 yrs. (b) Fuel Price = $0.84 /gal.

It should be noted that the capital charge represents an amortization of the acquisition cost of the ACV. Consequently, the out of pocket operating costs, once the vehicle has been purchased, are obtained by subtracting the capital charge from the total operating cost value.

The examination of Tables 6-14 and 6-15 indicates that the maintenance costs of the Voyageur ACV represent the largest of the four cost elements, at approximately 47 % of the total operating cost. Fuel, at 25 %, is the next largest cost contributor.

The expected operating lifetime of the Voyageur in the First District is 30 years, yielding a life cycle cost of $24.75 million per craft. In the Ninth District, the greater annual utilization is reflected in a 20 year craft lifetime estimate with a resulting life cycle cost of $24.00 million. The life cycle cost estimates are broken down into the four major cost elements in Table 6-16 for both the First and Ninth District employment of the Voyageur ACV. As a matter of interest, the ACV acquisition cost is less than one-fifth of the life cycle cost of the system.

Table 6 - 16

Voyageur ACV Life Cycle Costs for First and Ninth District Operations

Item	District			
	First		Ninth	
Capital Cost		$ 4 500 000		$ 4 500 000
Maintenance		11 547 000		11 302 400
Parts	$ 8 675 000		$ 9 374 400	
Labor	2 872 000		1 928 000	
Operating Crew		2 860 000		1 920 000
Fuel		5 807 000		6 274 800
Total		$ 24 714 000		$ 23 997 200

The life cycle cost summaries of Table 6-16 reflect a 30 year ACV operating lifetime in the First District, with a yearly utilization of 1 166 hours and a vehicle lifetime of 34 980 operating hours. For the Ninth District, the predicted 20 year ACV operating lifetime generates 37 800 operating hours from an annual utilization of 1 980 operating hours.

VII CONCLUDING REMARKS

The study which has been reported herein has examined the use of air cushion vehicles (ACV) for Coast Guard operations, with special emphasis placed upon the First and Ninth Districts. The Voyageur ACV as an existing design, has been given primary attention within the study. The high operating speed of the ACV, its zero draft and multi-terrain capability, together with its icebreaking capabilities, appear to provide vehicle operational characteristics of interest to the Coast Guard for the implementation of the Coast Guard programs. Endurance and towing capability limitations have emerged as the primary weaknesses of the ACV.

The study has addressed the performance, maintenance, cost, effectiveness and utilization properties of the air cushion vehicle in a manner which will provide a factual basis to assist the Coast Guard in assessing the desirability of including ACV units in the Coast Guard operating fleet.

The study has not attempted to develop a justification for the replacement of any Coast Guard vessel with an air cushion vehicle. The study has undertaken the analysis of First and Ninth District operations in order to prepare the credible scenarios which are necessary for a realistic assessment of the ACV relative to its potential effectiveness as an operating unit of the Coast Guard. As a case in point, the utilization analysis of Chapter V has developed the annual operating hour potential of the Voyageur ACV in the First and Ninth Districts.

VIII REFERENCES

1. U.S. Coast Guard, Abstracts of Operations, USCGC Snohomish (WYTM-98) for the Period 4/1/76 thru 6/30/79.

2. U.S. Coast Guard, Abstracts of Operations, USCGC Yankton (WYTM-72) for the Period 4/1/76 thru 6/30/79.

3. U.S. Coast Guard, Abstracts of Operations, USCGC Katmai Bay (WTGB-101) for the Period 1/1/79 thru 9/30/79.

4. U.S. Coast Guard, Domestic Icebreaking Operations - First District, Narrative Summaries (3) for the Years 1976-77; 1977-78; and 1978-79.

5. Bell Aerospace Canada, Voyageur Flatbed Air Cushion Vehicle, June 1973.

6. Decker, J.L., The Application of Air Cushion Configurations to Icebreaking, July 1978.

7. Canadian Coast Guard, Winter and Icebreaking Evaluations of the CCG Voyageur CH-CGA, Spring 1976.

8. Anon. Draft Report of the Katmai Bay Full Scale Icebreaking Tests, Available October 1979 to the Author

9. U.S. Coast Guard, Projected United States Coast Guard Icebreaking and Icebreaker Requirements 1975 - 2000, February 1975.

10. U.S. Coast Guard, Cutter Plan FY 1981 - 1990, 9 May 1979.

11. U.S. Coast Guard, MLB/SERV Unit Operational Study, 1 July 1972 - 31 December 1972, June 1973.

12. U.S. Coast Guard, letter, Capt. J. Wubbold to J.L. Decker, dated 15 November 1979.

13. Bell Aerospace Co., Analysis of a Search and Rescue Viking in the U.S. Coast Guard Ninth District, Report No. 7501-953003.

APPENDIX A

Voyageur Extended Mission Crew Accommodation Module

A brief conceptual design study of a crew accommodation module for use in extended missions of the Voyageur ACV in Coast Guard employment has been addressed. Since the Voyageur itself has been designed in modular form for ease of disassembly for air transport, it is considered to be desirable for the crew accommodation module also to be capable of disassembly from the Voyageur as a complete unit. The module width of 8 ft. is the same as that of the six central structural boxes of the Voyageur. A 7 ft. overall height was chosen for the crew accommodation module, providing for an inside floor to ceiling height of 6 ft. 8 in. An overall module length of 21.5 feet will utilize a bit more than half of the 40 ft. forward deck length of the Voyageur. The heating unit for the module is mounted externally, and extends 3 ft. in front of the module when the assembly is installed on the ACV.

The furnishings which are to be provided in the crew accommodation module are listed in Table A-1.

Table A - 1

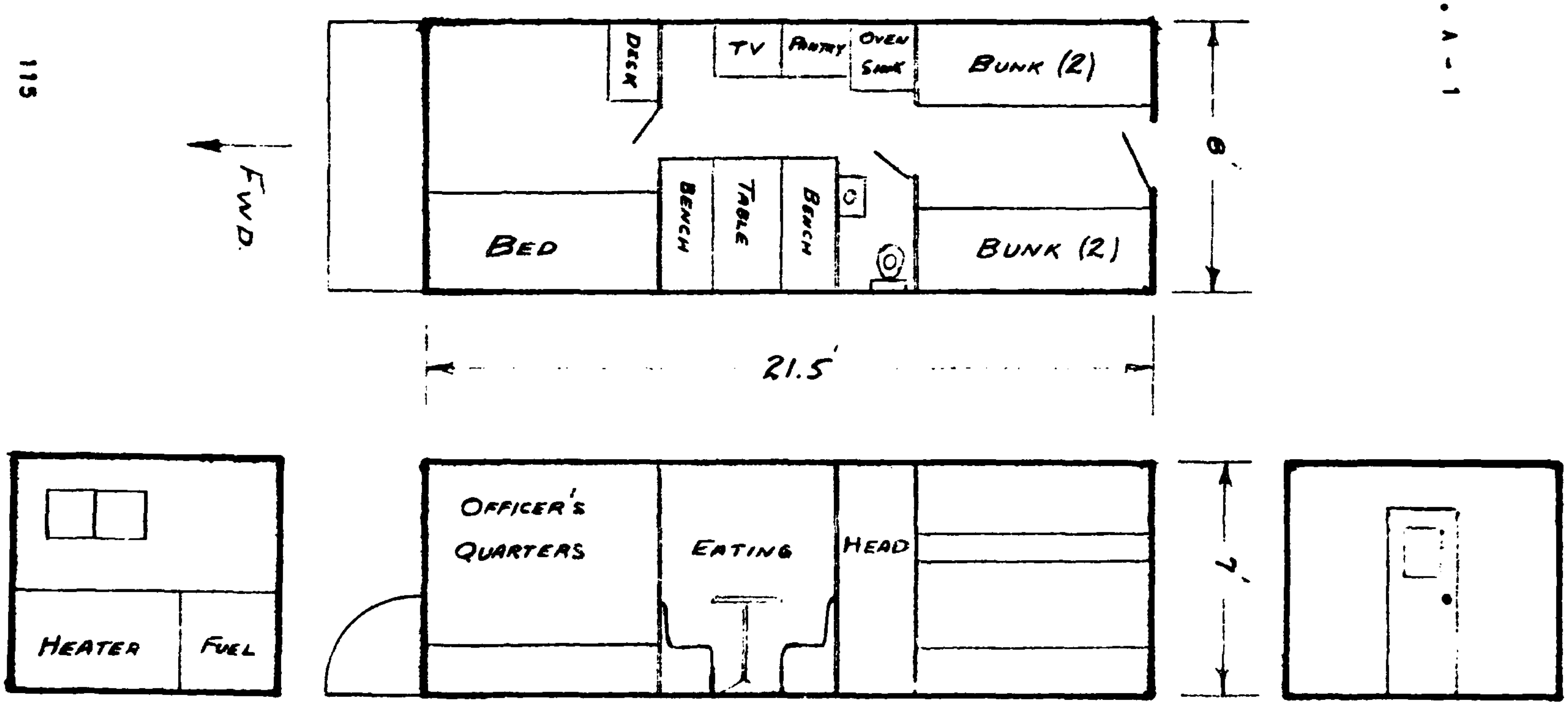
Voyageur ACV Extended Mission Crew Accommodation Module - Furnishings Listing

Galley	Microwave Oven Sink Refrigerator Storage Pantry
Eating Area	Booth with Table and 2 Benches for 4 Men
Sleeping	1 Bed in Quarters of Unit Commander 4 Bunks for Crew Members
Recreation	1 Television Set in Central Location 1 Television Set in Quarters of Unit Commander
Heat	Oil Fired Heater with Forced Air

Fig. A - 1

VOYAGEUR ACV

EXTENDED MISSION CREW ACCOMMODATION MODULE



The conceptual design has envisioned the use of welded **aluminum** hollowcore construction for the walls, floor, roof and ends of the module. Two structural bulkheads, also of hollowcore construction, are included to provide the necessary strength and rigidity to the assembly.

The module heater and fuel system are contained in an enclosure which is located at the forward end of the module. The heating equipment is located outside the module structure for safety reasons. Fig. A-1 depicts the general arrangement of the extended mission crew accommodation module.

The total weight of the crew accommodation module is estimated to be 4 200 pounds. The estimated cost of the module is $ 252 000. Since this cost estimate may appear to be relatively high for commonplace equipment, it is worthwhile to examine the cost considerations a bit further. The cost estimate given above is based upon a one unit production run. The effects of learning in the production process are well established as a powerful factor in cost reduction. Using the $ 252 000 first unit cost, the unit production costs are shown in Table A-2 for a range of production quantities and with a learning coefficient of 0.80.

Table A - 2

Effect of Production Quantity Upon Unit Cost

Learning Coefficient = 0.80

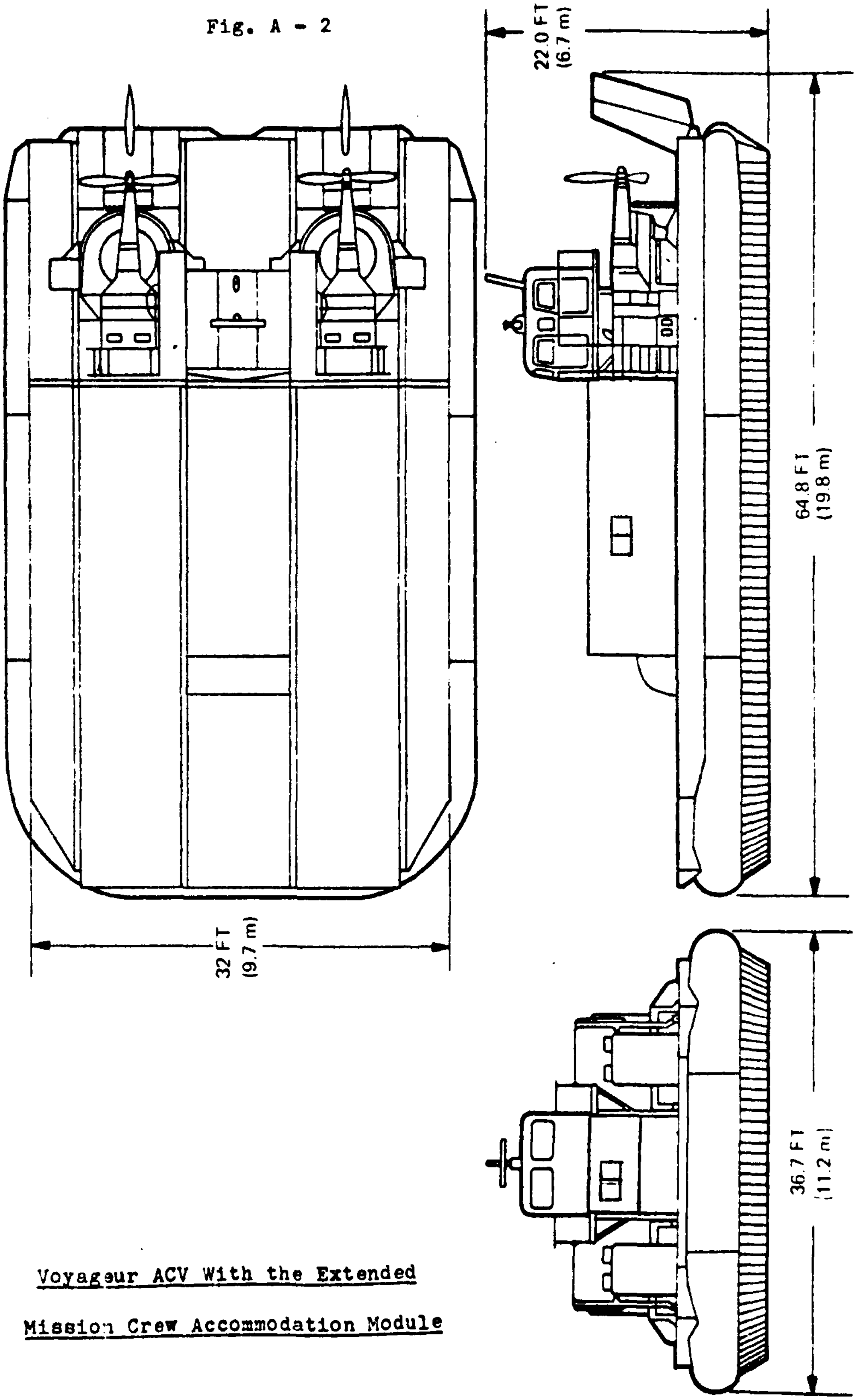
Number of Units	Unit Cost
1	$ 252 000
2	201 700
4	161 500
10	120 000
1 000	27 250
100 000	6 200

The production learning coefficients for two products as disparate as the Model T Ford and integrated circuits have production learning experience

which reflects a learning coefficient of 0.77. Consequently, it is evident from Table A-2 that the price which is estimated for the crew accommodation module is not grossly inconsistent with current commercial prices for production trailers which are built in substantial quantities. It is also clear that a major portion of the cost of a single module is related to the non-recurring activities such as engineering, testing, tooling and associated items.

The extended mission crew accommodation module is shown installed on the Voyageur ACV in the general arrangement drawings of Fig. A-2.

Fig. A - 2



Voyageur ACV With the Extended

Mission Crew Accommodation Module